UNIVERSIDAD COMPLUTENSE DE MADRID

FACULTAD DE CIENCIAS ECONÓMICAS Y EMPRESARIALES
Departamento de Economía Aplicada II
(Estructura Económica y Economía Industrial)

TESIS DOCTORAL

La internacionalización de la actividad innovativa en las empresas multinacionales
Un análisis geográfico y sectorial

MEMORIA PARA OPTAR AL GRADO DE DOCTOR

PRESENTADA POR

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Madrid, 2014

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Doctorado Interuniversitario con Mención de Calidad en
ECONOMÍA Y GESTIÓN DE LA INNOVACIÓN (DEGIN)

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Memoria para optar al grado de

DOCTOR
con Mención Europea
presentada por

ROBERTO MAVILIA

bajo la codirección de los doctores

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UNIVERSIDAD COMPLUTENSE
MADRID

FACULTY OF ECONOMICS AND BUSINESS

Department of Applied Economics II
Economic Structure and Industrial Economics

Interuniversity Ph.D. Program with Quality Mention in
ECONOMICS AND INNOVATION MANAGEMENT (DEGIN)

The internationalization of innovative activity in multinational enterprises

A geographic and sectoral analysis

Dissertation submitted in partial fulfillment
of the requirements for the degree of

DOCTOR OF PHILOSOPHY
with European mention
by

ROBERTO MAVILIA

under the direction of the supervisors

JOSÉ MOLERO ZAYAS
FRANCO MALERBA

Esta investigación ha sido financiada indirectamente (03/01/2005 – 13/05/2010) por el Gobierno italiano (Ministero della Giustizia) en virtud del artículo 52, apartado 57, de la Ley italiana n. 448/2001, integrado por el articulo 2 de la Ley italiana n. 476/1984.

This research has been indirectly supported (03/01/2005–13/05/2010) by Italian Government (Ministero della Giustizia) under article 52, paragraph 57 of the Italian Law no. 448/2001, that integrated article 2 of the Italian Law no. 476/1984.

What can I give back to God for the blessings he's poured out on me?
I'll lift high the cup of salvation – a toast to God – and I'll pray in the name of God
I'll complete what I promised God and I'll do it together with his people
(Psalm 116, 12–14)

Acknowledgements

My sincere gratitude goes to my supervisor, José Molero. Without his support and active participation in the first step of the process, this thesis may never have been completed. Not only did he give generously of his time and expertise while I was studying in Spain, but he also remained involved when I returned to Italy. Thank you very much for your encouragement and understanding over these past years.

I also want to thank my co–supervisor, Franco Malerba, that made me realize how interesting these fields can be and let me join his research group to actively contribute to its advancement. I want to thank him because of this and because he always allowed me a great degree of freedom in choosing my research topic and, at the same time, he always provided me his precious guidance and suggestions, especially when the good results seemed farther away and harder to reach.

All my colleagues at the CESPRI, KITeS and now CRIOS are thanked for creating very enjoyable surroundings. Numerous discussions over coffee, lunch or beer have been an important and pleasant diversion from economics.

I am indebted to the GLOBE*lics* Doctoral Academy, in particular to Bengt–Åke Lundvall and Shuling Gu, for the education during my stay and the various members of the GLOBE*lics* network whom I had the opportunity to work. They provided a friendly and cooperative atmosphere at work and also useful feedback and insightful comments on my research work. Many of the ideas and findings in this thesis originated from discussion with and inspiration by them.

As a student of the doctoral programme, I have been surrounded by wonderful colleagues. Autonomous University first and Complutense later, have provided a rich and fertile environment to study and explore new ideas. I vividly remember the challenging but stimulating first year of course work in Madrid. I was lucky to have had friends who helped me in keeping my academic and social life in balance. I enjoyed very much the relaxing hours I spent with Christian Cancino del Castillo, Dario Milesi and Ricardo Zarate. I expand my thanks to Javier who shared his residence with me during my stay in Madrid and extended brotherly love towards me.

I would also like to thank my family for the support they provided me through my entire life, my older brother Mammo and in particular, I must acknowledge my wife and best friend, Daniela, without whose love and encouragement, I would not have finished this thesis. This thesis is dedicated to her and to the two wonderful creatures, Elisa and Giulia, that our Lord has given us.

Acronyms

ACEA	European Automobile Manufacturers' Association
BBFN	Broadband/Fixed Network
BRICS	Brazil, Russia, India, China and South Africa
DRAM	Dynamic Random Access Memory
EMN	Empresas Multinacionales
EPO	European Patent Office
FDI	Foreign Direct Investment
GPRS	General Packet Radio Service
HBA	Home Base Augmenting
HBE	Home Base Exploiting
HHI	Herfindahl–Hirschman index
I+D	Investigación y Desarrollo
ICT	Information and Communication Technology
ICTEB	Index of Technological Complexity of Patents
IGI	Index of Inventors' Group Internationalization
IPC	International Patent Classification
IPR	Intellectual Property Rights
ISIC	International Standard Industrial Classification of all economic activities
ISTEM	Index of Technological Specialization for MNE
ISUB	Index of Utilization Specificity of Patents
IT	Information Technology
MNE	Multinational Enterprises
OECD	Organization for Economic Cooperation and Development
OEP	Oficina Europea de Patentes
OST30	Observatoire des Sciences and des Techniques classification
PATSTAT	Worldwide Patent Statistical Database
PRY	Prority year
R&D	Research and Development
S&T	Science and Technology
SRAM	Static Random Access Memory
UMTS	Universal Mobile Telecommunications System
UNCTAD	United Nations Conference on Trade and Development
USPTO	United States Patent and Trademark Office

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Summary

Introduction

One of the most important elements affecting innovation performance are people who generate ideas, discover technological opportunities, solve technical problems and develop manufacturing processes and prototypes. Ever since the corporate research and development (R&D) became an important strategic arm of private firms, inventive processes became more collective than individual.

The formation of R&D teams can be traced back to heterogeneity in terms of geography, sector, ethnicity and culture, to mention a few. This heterogeneity of the team is one of the key drivers of innovation. However, it may also have its drawbacks.

Objectives and research questions

The current dissertation aims to understand how the degree of the intensity of international collaboration in inventive activities has varied over the years.

Specifically, it addresses the following research questions concerned with the differences across sectors and countries:

1. What was the path of internationalization of groups of inventors in the last thirty years?
2. Does the speed of internationalization, measured as geographical concentration of the group of inventors, differs across sectors?
3. Does the behavior of multinational enterprises (MNEs) in internationalizing their inventive activities differ from that of the whole sectors?
4. How different is the behavior of MNEs, in their own sector, with respect to their technological specialization of inventive activity?
5. How different is the behavior of MNEs, in their own sector, with respect to their technological complexity of inventive activity?

The first part of the research work (Chapter 1) describes the most important contributions in the direction of having a comprehensive picture of the organization of knowledge intensive activities in the global landscape. In order to understand

knowledge intensive activities, the focus is on MNEs, the most important unit of analysis for technological transfer in the global environment.

The second part (Chapter 2) analyses the trend of internationalization of inventive activity over a certain fixed time period, highlighting the differences between advanced countries and the developing ones.

In the final section (Chapter 3) we adopt an approach of estimating the degree of internationalization within countries, within sectors and within 20 MNEs identified as the top five in four important sectors: automotive, pharmaceuticals, telecommunications and semiconductors.

Methodology

The empirical part of this study builds upon a subset of a larger dataset constructed and maintained by CRIOS at Bocconi University (Milan, Italy). We take advantage of a unique source of firm-level innovation data derived from European patent records.

In order to fulfill the objective of understanding the extent of internationalization present in the inventive activities, our research work makes a fruitful attempt at calculating internationalization indexes. Here is the detail of the four indices used:

1. Index of Inventors' Group Internationalization (IGI): This index measures the internationalization of a research group.
2. Index of Technological Specialization for MNEs (ISTEM): this is an index of concentration of the patents granted to a multinational company in a given year in terms of OST 30 technological class.
3. Index of Utilization Specificity of Patents (ISUB): this index can be seen as an inverse index of the general purpose degree of a technology. It measures the concentration of four-digit IPC macro-classes of every patent.
4. Index of Technological Complexity of Patents (ICTEB): this index is also based on an HHI-based index of concentration.

Results

The results are derived from the empirically analysis conducted on different sectors with the help of patent data statistics.

A comprehensive explanation of both the phenomena of R&D globalization and internationalization within MNEs is provided. The detailed explanation of prior scholarly work helps conclude that, despite geographical and cultural distances, a team which constitutes of researchers with diverse background may generate highly innovative outcomes.

Here it follows a brief description of each index behavior along in the observed sample and a sketch of the underlying analysis is added.

The degree of internationalization, assessed on the basis of teams of researchers with heterogeneous geographical origins, exhibits an almost exponential increase over the whole observed period. However, despite the sharp increase over time, the average level of heterogeneity was always quite low.

The ISTEM showed whether a high level of specialization is observed across all sectors or it is a specific feature of few of them. The five years index suggested that semiconductor and telecommunication are the most specialized sectors. On the contrary, Automotive and Pharmaceuticals present a low specialization level, suggesting either that patents belonging to a specific sector could be assigned to many different classes or that there are no prevalent classes assigned to their patents.

The ISUB gave very clear and comprehensive idea of the last five years trend. Over the chosen time span it is possible to observe different kinds of behavior.

The last index, the ICTEB – capturing technological complexity of patents, showed a general decreasing trend in each of the analyzed sectors.

Two interpretations could be drawn from this decreasing pattern:

- An increase in the asymmetry between classes cited by patents.
- A decrease in the number of cited classes.

In the first decades of the sample the vast majority of sectors clearly shows a decreasing trend in the technological complexity of the patents; in addition, this behavior is evident also at firm level and not only when we aggregate MNEs performances to obtain sectorial ones. To the contrary, the situation changes when we focus in the last 10 years: behavior of the ICTEB along sectors in much more heterogeneous. In particular, it is possible to observe that the number of sectors displaying an increasing technological complexity in the inventions they patent (Pharmaceuticals and Telecommunications) is equal to number of sectors with decreasing ICTEB (Automotive and Semiconductor).

After integrating individual firm performances in the sector-level version of the index, what emerges is that dissimilarities are much greater than affinities, with the exception of technological complexity of the patents, which is the sole dimension along which all the analyzed sectors exhibit the same (decreasing) pattern.

Another interesting dimension is given by a comparison of the variability around sectorial-trends between one sector and another. Proceeding along this stream and keeping fixed the period of analysis we notice that, with respect to the IGI index, the Semiconductors is the sector with the highest degree of homogeneity, having all the relevant MNEs displaying very similar patterns, while in Automotive and Pharmaceuticals MNEs show very contrasting behaviors of the index.

Moving to the ISTEM the picture is reversed. MNEs with most similar behavior are those operating in the Pharmaceuticals while automotive and semiconductor firms show extremely heterogeneous trends. Focusing instead on the ISUB, the index measures the degree of utility specialization. It is analysis highlights the similar behavior amongst the while Semiconductors and Telecommunications show a very heterogeneous pattern, with always no more than 2 firms over 5 having an analogous trend.

With regard to the ICTEB, Semiconductors and Telecommunications are again the two sectors presenting a higher degree of heterogeneity in the behavior of their relevant MNEs; while in the other two sectors each firm displays a pattern very similar to the other.

While concluding it is interesting to underline that apart from sectorial differences in the aggregate value of the four indexes proposed in this work, there exists an additional source of intra-sectors heterogeneity. It is given by the variability of the behavior among MNEs within each sector. In general Telecommunications and, in particular, Semiconductors are the two sectors with a more pronounced variability, having firms performing in very different ways.

Conclusions

Firstly, we have explored and analyzed the main trends of internationalization of R&D team in the MNEs. The main contribution is the development of an index which helps in understanding the internationalization of knowledge production and diffusion.

Secondly, as the dataset used covers a period of nearly 29 years, the results help in having a long term analysis. While performing the analysis on the basis of geographical index we divide the patents according to the presence of inventors from BRICS and from the Asian Tigers, and further to their technological class.

Furthermore, the results are explored in four big sectors: Automotive, Pharmaceuticals, Semiconductors, and Telecommunications. In addition to considering four key sectors, the structural fluctuations owing to mergers and acquisitions experienced by every sector are also considered. This approach is able to deliver more reliable results compared with the previous ones which assigned patents to parent companies assuming no structural changes over time. The problems linked to the older approach are based on the intrinsic characteristics of patenting activity which is strategic and could be influenced by changes in the group structure. The approach adopted in this chapter rules out the emergence of such problems.

Finally, our approach provides an additional dimension of the analysis which constitutes in the comparison of the intra-sectors heterogeneity in MNEs' behavior along the proposed dimensions. To best of our knowledge this kind of analysis is not encompassed by the existing literature.

Resumen

Introducción

Uno de los elementos más importantes que afecta al rendimiento de la innovación son los individuos que generan las ideas, descubren oportunidades tecnológicas, resuelven problemas técnicos, y desarrollan procesos de fabricación y prototipos. Desde que las actividades de investigación y desarrollo (I+D) se convirtieron en un arma estratégica importante de empresas privadas, los procesos de invención se volvieron más colectivos que individuales.

La formación de equipos de I+D tiene un origen muy heterogéneo en términos de geografía, sector, grupo étnico y cultural, por mencionar algunos. Esta heterogeneidad del equipo es uno de los factores clave de la innovación. Sin embargo, esto también puede tener sus inconvenientes.

Objetivos y preguntas de investigación

El objetivo de este trabajo de investigación es entender cómo el grado de intensidad en la colaboración internacional de las actividades inventivas ha variado a lo largo de los años.

Específicamente, este trabajo de investigación busca contestar a las siguientes preguntas relacionadas con la diferencia entre sectores y países:

1. ¿Cuál fue la tendencia de la internacionalización de los grupos de inventores en los últimos treinta años?
2. ¿La velocidad de la internacionalización, medida como la concentración geográfica del grupo de inventores, difiere entre sectores?
3. ¿El comportamiento de las empresas multinacionales (EMN) en la internacionalización de sus actividades inventivas difiere de la de los sectores enteros?
4. ¿Cómo se diferencia el comportamiento de las EMN, en su propio sector, en relación con su especialización tecnológica de la actividad inventiva?

1. ¿Cómo se diferencia el comportamiento de las EMN, en su propio sector, en función de su complejidad tecnológica de la actividad inventiva?

La primera parte del trabajo de investigación (Capítulo 1) describe las contribuciones más importantes a fin de tener una visión global de la organización de las actividades intensivas en conocimiento. Centrando la atención en las EMN, la unidad más importante de análisis para la transferencia tecnológica en el medio ambiente global.

La segunda parte (Capítulo 2) analiza la tendencia a la internacionalización de la actividad inventiva en un determinado período de tiempo, poniendo de relieve las diferencias entre los países avanzados (OECD) y de los países en desarrollo. En la sección final (Capítulo 3) se adopta un enfoque para estimar el grado de internacionalización entre los países, entre los sectores y entre 20 empresas multinacionales identificadas entre las cinco primeras en cuatro importantes sectores: automotriz, farmacéutico, telecomunicaciones y semiconductores.

Metodología

La parte empírica de este estudio se basa en un subconjunto de datos de una gran base de datos construida y mantenida por el Centro CRIOS de la Universidad Bocconi de Milán (Italia). Nos aprovechamos de una fuente única de datos sobre innovación a nivel de empresas derivadas de registros de patentes europeas.

Se propone el diseño de 4 índices para medir la internacionalización. Los cuatro índices utilizados son:

1. Índice del Grupo de Internacionalización de Inventores (IGI): este índice mide la internacionalización de un grupo de investigación.
2. Índice de Especialización Tecnológica de las EMN (ISTEM): es un índice de concentración de las patentes concedidas a una EMN en un año dado, en términos de OST 30 clase tecnológica.
3. Índice de Utilización Especificidad de Patentes (ISUB): este índice puede ser visto como un índice inverso del grado de propósito general de una tecnología.
4. Índice de Complejidad Tecnológica de Patentes (ICTEB): este índice se basa en un índice de concentración HHI-based.

Resultados

Los resultados se derivan del análisis empíricamente llevado a cabo en los diferentes sectores con la ayuda de las estadísticas de datos de patentes.

Se proporciona una explicación completa del fenómeno de la globalización e internacionalización de I+D dentro de las EMN. Una justificación detallada del trabajo académico en esta área ayuda a concluir que, a pesar de la distancia geográfica y cultural, la constitución de un equipo de investigadores con diferentes habilidades y diversos conocimientos puede generar resultados muy innovadores.

A continuación se encuentra una breve descripción sobre el comportamiento de cada índice con un boceto del análisis subyacente.

El cálculo de la internacionalización sobre la base de los equipos que tiene miembros con diferentes orígenes geográficos muestra un aumento casi exponencial de la internacionalización de los grupos de inventores durante todo el período observado. Sin embargo, el nivel medio de esta heterogeneidad fue siempre bastante bajo.

El ISTEM de cinco años sugiere que los semiconductores y telecomunicaciones son los sectores más especializados. Por el contrario, automóviles y productos farmacéuticos presentan un bajo nivel de especialización, lo que sugiere o bien que las patentes que pertenecen a un sector específico podrían ser asignados a diferentes clases o que no existen las clases dominantes asignados a sus patentes.

El ISUB dio una muy clara y completa idea de la tendencia de los últimos cinco años. Durante el período de tiempo elegido es posible observar diferentes tipos de comportamiento.

El último índice, el ICTEB – captando la complejidad tecnológica de patentes– mostró una tendencia a la disminución general de cada uno de los sectores analizados.

Dos interpretaciones se pueden extraer de este patrón decreciente:

- Un aumento de la asimetría entre las clases citadas por las patentes
- Una disminución en el número de clases citadas.

Durante las primeras décadas de la muestra en la gran mayoría de sectores se muestra claramente una tendencia a la disminución en la complejidad tecnológica de las patentes y, además, este comportamiento es evidente también a nivel de empresa, y no sólo cuando agregamos las actuaciones de las EMN para obtener los sectoriales. Al contrario, cuando nos centramos en los últimos 10 años: el comportamiento del ICTEB a lo largo de los sectores son mucho más heterogéneo. En particular, es posible observar que el número de sectores que muestran un aumento de la complejidad tecnológica en las invenciones que la patente (Productos farmacéuticos y Telecomunicaciones) es igual al número de sectores con la disminución de ICTEB (automotriz y semiconductores).

Tras la integración de las actuaciones específicas de una empresa en la versión a nivel sectorial del índice, lo que surge es que las diferencias son mucho mayores que las afinidades, con la excepción de complejidad tecnológica de las patentes, que es la única dimensión a lo largo de la cual todos los sectores analizados exhiben el mismo patrón (decreciente). Otra dimensión interesante está dada por una comparación de la variabilidad en torno a las tendencias sectoriales, entre un sector y otro. Manteniendo fijado el periodo de análisis se observa que, con respecto al índice de IGI, los semiconductores es el sector con el mayor grado de homogeneidad, mientras que las empresas automotrices y de productos farmacéuticos muestran comportamientos del índice muy contrastantes.

Pasando a la ISTEM la imagen se invierte. Las EMN con un comportamiento más parecido son las que operan en los productos farmacéuticos, mientras que las empresas automotrices y semiconductores muestran tendencias muy heterogéneas. Centrándose en cambio en el ISUB, el análisis pone de manifiesto el comportamiento similar entre los mientras que Semiconductores y Telecomunicaciones muestran un patrón muy heterogéneo, siempre con no más de 2 firmas de más de 5 que tienen una tendencia análoga.

Con respecto a los ICTEB, Semiconductores y Telecomunicaciones son de nuevo los dos sectores que presentan un mayor grado de heterogeneidad en el comportamiento de las EMN importantes, mientras que en los otros dos sectores cada empresa muestra un patrón muy similar a la otra.

Al concluir, es interesante destacar que, aparte de las diferencias sectoriales en el valor agregado de los cuatro índices propuestos en este trabajo, existe una fuente adicional de heterogeneidad intra – sectorial. Se administra por la variabilidad del comportamiento entre las EMN dentro de cada sector. En las telecomunicaciones en general y, en particular, semiconductores son los dos sectores con una variabilidad más pronunciada, tras llevar a cabo las empresas de muy diferentes maneras.

Conclusiones

En primer lugar, hemos estudiado y analizado las principales tendencias de la internacionalización de equipos de I+D en las EMN. La principal contribución es el desarrollo de un índice que ayuda a comprender la internacionalización de la producción y difusión del conocimiento.

En segundo lugar, ya que el conjunto de datos utilizado cubre un período de casi 29 años, los resultados ayudan a tener un análisis profundo. La realización del análisis sobre la base del índice geográfico profundiza aún más el análisis y divide las patentes de acuerdo con la presencia de los inventores de países BRICS y de los tigres asiáticos, y aún más en su clase tecnológica.

Además, los resultados se analizan en cuatro grandes sectores: automotriz, productos farmacéuticos, telecomunicaciones y semiconductores. También se considera las fluctuaciones estructurales debido a las fusiones y adquisiciones experimentadas por cada sector. Este método es capaz de ofrecer resultados más confiables en comparación con las anteriores que asignan las patentes a las sociedades matrices suponiendo que no hay cambios estructurales en el tiempo. Los problemas relacionados con el enfoque más antiguo se basan en las características intrínsecas de la actividad que es estratégica y podría estar influenciada por los cambios en la estructura del grupo de patentes. Bajo el enfoque adoptado en este capítulo se descarta la aparición de estos problemas. Por último, nuestro enfoque ofrece una dimensión adicional del análisis, que constituye en la comparación de la heterogeneidad intra–sectorial del comportamiento de las EMN a lo largo de las dimensiones propuestas. Para nuestro conocimiento este tipo de análisis no está abarcado por la literatura existente.

Chapter 1
The organization of knowledge intensive activities in the global landscape: a literature review

1.0. Abstract

The globalization of R&D and more generally the internationalization of innovation and inventive activities has gained in the last decades the attention of the majority of the scholars active in the field of the economics of innovation. While this phenomenon has been analyzed in depth and many theories have been recognized to be fundamental in the understanding of the processes, the causes and the consequences of this important trend, several aspects remain still uncovered.

In this chapter we are going to mention and comment the most important contributes in order to have a comprehensive picture of the phenomenon, with a particular focus on probably the most important unit of analysis for technological transfer in the global environment, that is MNEs.

1.1. Introduction

MNEs use a variety of strategies that allow knowledge to cross national borders and to diffuse, among these strategies foreign direct investment (FDI) is only one option: trade of technology–embedded goods, technology licensing, cross patenting activities and international scientific and technological collaborations are increasing in the last decades thanks to the pivotal role played by MNEs (Narula and Zanfei, 2004). Indeed, multinationals are frequently involved in cross–border R&D projects and thanks to their global nature they are able to access and manage a very diverse pool of knowledge sources.

Moreover, MNEs engage in technological co–operation with partners from different countries, working closely with distant industrial actors in order to generate know–how and innovations. Archibugi and Michie (1995) suggested that three groups of economic actors are responsible for the global transmission of technology across national boundaries. These categories are not mutually exclusive and the proof of the importance of MNEs lies in the fact that MNEs are the only typology of economic actor performing at the same time all the activities that are at the basis of the taxonomy developed by the two former authors. Hence, MNEs are the only institution that can manage and control the global generation of innovation without crossing their boundaries.

Indeed following the authors, there is:

- The first category group's enterprises that commercialize technologies developed in the domestic countries. The trade of technological products and capital goods, such as specialized tools and machinery or of other knowledge intensive goods, is responsible for technological transfer. The positive correlation between R&D intensity and export intensity seems to confirm that the link between international trade and knowledge diffusion has strengthened over time (Archibugi and Iammarino, 2002). Gains in efficiency embodied in the new equipment and other capital goods are reflected in greater outputs, reduced labor and greater quality (Hoekman *et al.*, 2006).
- The second group consists of actors that are involved in technical and scientific collaborations, such as multinational firms, research centers and universities. Private companies have significantly increased the use of cooperative strategies or the so called "strategic technological partnering". In the recent years these collaborations have changed, in the 1970s technological alliances were substantially achieved through equity agreements, accounting for 70% of the total number of collaborations. However, this percentage declined in the last decades, falling to 10% in the 1990s in favor of non–equity technological partnering. In particular, increasing knowledge flows in scientific and technological collaborations are due to the prominent role of MNEs: alliances tend to be highly correlated with the presence of large firms with ample resources in technology intensive sectors (Narula and Zanfei, 2004).
- The third and probably the most important vehicle for knowledge diffusion across national borders is FDI. Nothing to say, MNEs are clearly the only economic actor able to sustain the expenses of locating production and R&D

facilities abroad. The importance of R&D performed abroad by foreign affiliates has been generally growing in most host economies over 1990s, nevertheless, most R&D and patenting activities are still largely concentrated in MNEs' home countries and in few host countries. Indeed, over 90% of the R&D expenditures of most MNEs are located within the Triad (Cantwell, 1995).

MNEs are the ones that are in the best position for benefiting and managing the global diffusion of innovation and R&D and are able to sustain all the efforts directed towards the exploitation of important opportunities coming from the internationalization of innovation–related activities. Traditionally R&D operations were concentrated in large, central laboratories located within the domestic boundaries of the company, but since the 80's inventive efforts are increasingly performed abroad. Generally speaking, the literature has tried to explain this trend by stating that the globalization of R&D has been perhaps a consequence of the globalization of production (Florida, 1997). It is Interesting to know that, the location decisions based on production–related advantages, such as cost advantages arising from cheap labour in developing countries, fail to explain and to motivate the entire process of corporate R&D decentralization (Blanc and Sierra 1999).

There is in any case, as suggested by Blanc and Sierra (1999), a trade–off between geographical dispersion and geographical concentration of R&D: a geographically centralized organization of inventive activities implies no duplication costs of innovation efforts, economies of scale and effective control over the activities, in that way exploiting as much as possible internally produced knowledge. On the other side, however, the company has to absorb new knowledge coming from outside and cannot rely only on internal knowledge sources, but has to build and exploit links with other important actors, in particular customers, new markets, suppliers, universities, research centers and competitors.

1.2. Benefiting from the internationalization of R&D through FDIs

Once a firm realizes that it has the capability to satisfy the demand in a foreign country, it will evaluate different options for exploiting this capability: it may decide to open up its own subsidiary in the foreign country or to contract out the activity concerned. In this respect, the important commitment represented by the FDI should be evaluated in the face of the opportunities offered by the host economy and the option value of deferring an FDI commitment under conditions of high uncertainty (Rivoli and Salorio, 1996). Two key motivations have been proposed by the literature (Kuemmerle, 1999) in order to explain FDI in research and development laboratories. Firstly, an MNE could face an increasingly sophisticated demand when establishing its production facilities abroad, often with the need to adapt products and services to the local demand.

For this reason, R&D facilities are required to be established in proximity to factories, since product have to be modified and improved to meet the local customers. This strategy is called home base exploiting (HBE). However, lot of scholars in the literature (Cantwell, 1995; Frost, 2001; Le Bas and Sierra, 2002; von Zedwitz and Gassmann, 2002) have pointed out that MNEs might choose regions and nations that are particularly advantageous not because of the link to production facilities and in turn to local demand, but because of the opportunity of benefiting from spillovers from other active actors in the local economy [home base augmenting (HBA) strategy].

Indeed, knowledge spillovers from organizations such as research centers, universities, innovative competitors and government agencies involved in the production of knowledge and in R&D may well constitute a big opportunity for MNEs and an important advantage over non–multinational companies in R&D that do not engage in direct investment in foreign economies. In order to fully understand the importance of the phenomenon of knowledge spillovers, the well–known distinction between tacit and codified knowledge can help in understanding why it is important to interact actively with local sources of knowledge. Briefly speaking, knowledge and ideas cannot be codified easily or at low cost, since it has a tacit component that cannot be easily extracted from the context and the locus of innovation (Nonaka *et al.*, 1995). Tacit knowledge can be acquired only by interacting and sharing the presence in the same context where innovation is being developed.

This distinction obviously suggests the crucial importance of geographical proximity in order to benefit from knowledge spillovers and therefore the advantage provided by the physical location of R&D facilities close to other knowledge sources. Interactions, as already stated, involve institutions and not just economic actors active in the same industry or technological field: universities and research centers provide graduating students and scholars that embody a strong component of tacit knowledge (Audretsch and Keilbach, 2007). Hence, accessing research institutions and knowledge pools with particular expertise in certain disciplines might be an important driver for R&D internationalization.

As already stated human capital is capable of transferring tacit knowledge, as a result multinational companies tend to move their own people in order to transfer knowledge on an international scale. They send delegates from the parent company in order to diffuse the accumulated knowledge, which is recombined with the new sources of knowledge of the hosting economy. Additionally visiting researchers and analysts can be sent to subsidiaries to acquire and bring back all the information critical to central R&D activities, or *vice–versa* can be sent by the subsidiary to the central R&D site to absorb the knowledge required to run the activities in the host economy.

Following this reasoning, it appears evident that the MNEs' knowledge base is not only the outcome of the activities performed in the domestic country, but also of the host economy's innovation system, internalized by the firm (Criscuolo *et al.*, 2005). However, developing and maintaining strong linkages with external network could be extremely time consuming and costly: that is probably the reason why multinational companies, that are not financially constrained as small firms are, might be the only typology of firm in the position to build and exploit these kinds of strategies. Of course, the dependence of MNEs on national innovation system that host R&D departments might constitute as well an additional source of risk.

1.3. Internationalization and national innovation systems

Innovation and knowledge are spread in several ways across nations: import of capital goods and market transactions are potential sources of technological transfer. The acquisition of equipment as means of technological transfer can be relevant for those states that have been characterized by low levels of expenditures in R&D.

This reasoning can also be applied to sectors that, in Pavitt's words, are supplier dominated: for example, a state in which a relevant role is played by sectors like textiles or tourism, the supply of technology–intensive equipment can be an important source of knowledge transfer. On the other side knowledge can be obtained also through market transactions (Hoekman *et al.*, 2006), that is especially through technology licensing agreements, the hiring of consultants and other ways of interacting with external sources of technological sources: going back to the concept of Marshallian economies, social interaction and direct observation of other more innovative actors may constitute a means of knowledge transfer.

The establishment of R&D facilities abroad through FDI is probably the most important channel for international knowledge transfer. This argument has found substantial interest in the academic community as well across governments, as the potential for technological transfer and in turn augmented productivity and knowledge acquisition has been recognized to be relevant. By attracting inward FDI, developing countries hope to benefit from positive externalities generated by MNEs activities in the host economies.

We already reported the two major arguments for the establishment of innovative activities abroad, now we are going to analyze and report the most important contributions in the literature on the effects that the globalization of innovation has generated for the countries involved in this wide phenomenon. It is quite straightforward to see that the benefits of technology transfer thanks to MNEs are two–fold: firstly, these companies may introduce new technologies in the host country; secondly, the technologies and the knowledge that is already used by the company can become accessible also to local firms thanks to R&D spillovers (Baldwin *et al.*, 2005). Furthermore, the specific type of technology that the MNEs chooses to install in a foreign affiliate may also affect the potential for spillovers (Braconier *et al.*, 2001).

Firstly, the technological gap between different regional or national innovation systems and the foreign subsidiaries might be relevant and consequently the possibility of benefiting from spillovers, ceteris paribus, may vary. Indeed, Abramovitz (1986) argues that capabilities are important for absorbing new technologies and turns our attention back to the famous concept of absorptive capacity (Cohen and Levinthal, 1989). Firms that do not invest sufficiently in research and development activities may lack the capability to exploit knowledge spillovers, not recognizing and not being able to capture the value of the technology.

Indeed, multinationals surely transfer technology and knowledge to their subsidiaries, but is this true also for the firms and the other players in the host economy? Some arguments support the positive role of the presence of MNEs companies in host economies without taking into account the importance of knowledge spillovers, in that the entry of a more competitive company in the market should encourage the others within the same sector to improve their performance and competitiveness. In this sense, companies that are not able to catch up with the leading ones are likely to be crowded out of the market (Stancik, 2007).

Other important observations deserve to be mentioned in order to fully understand the variables that may affect the potential and the relevance of FDI in diffusing knowledge and innovation, in particular the degree of interaction between the MNE and the other agents in the host country. We here focus on the two forms of spillovers that represent the main means of technological transfer: vertical and horizontal spillovers from FDI. The first modality of transfer relates to companies that are active in different sectors along the supply chain.

Vertical spillovers are the effects carried by FDI across industries through contact between MNEs' subsidiaries and local suppliers of intermediate products or clients that are active in the final markets. On the other hand, the second modality considers spillovers among economic players that are direct competitors in the market. The reason why we believe this is an important distinction is because the modes of diffusion of knowledge and technology, as well as the benefits and the potential for transfer might substantially differ when we categorize spillovers in that way. Moreover, it helps to understand why the debate on international spillover of R&D activities is still controversial. As said, a strong research tradition exists that tests the extent of such spillovers by analyzing whether foreign presence of MNEs' subsidiaries has induced higher levels of productivity to local firms in the same sector.

These studies produced mixed results: the controversy in our opinion arises from the fact that FDI effects can be both negative and positive in the case of horizontal spillovers. It seems that in the case of vertical relationships between foreign subsidiaries of MNEs and client or supplier firms, the effects may be always positive or absent, but never negative. On the other side negative effects may indeed be relevant in the case of increased competition in final goods markets where incoming firm are able to monopolize them, thereby suffocating local unproductive competitors by retaining critical knowledge within the firm's boundaries to protect the competitive advantage (Aitken *et al.*, 1997).

In the case of vertical spillovers, collaborations and market transactions between actors are often accompanied by the imposition of higher requirements in terms of quality, productivity and the use of the latest technologies by foreign affiliates. In simple words, foreign subsidiaries have strong interests in having competitive and advanced partners in the host economy and to reach the target, they might be willing to share know how and competences with them.

For that reason, the magnitude of vertical spillovers, which benefit both the foreign subsidiaries and the local firms, could be reasonably bigger than the one generated by horizontal spillovers. In case of horizontal spillover relationships with other actors operating in the same market from the host economy creates a competitive effect which reduces the incentives to engage in relationships and in knowledge transfer.

However, all the forms of knowledge could not be shared with domestic enterprises in the case of vertical spillovers. As anticipated, the other important determinant of the magnitude of spillover is the size of the technological gap between domestic and foreign firms, that is, spillover magnitude appears to depend on the host country ability to absorb the foreign technologies, again when the technological gap is large companies might not be able to catch up with leading companies.

1.4. Attraction of R&D and potential for knowledge diffusion

Given the importance of knowledge and technology spillovers, it is not a surprise that countries have implemented innovation policies that try to promote and attract foreign investments. The main local drivers are the availability of world class research infrastructures and skilled labor, as well as a dynamic national innovation system. A dynamic national innovation system is characterized by a high degree of interdependence amongst actors involved in innovation activities (Cantwell and Iammarino, 2003). Moran (1998) suggests that a liberal economic climate tends to attract more dynamic FDIs, with a large scale of investments and at the cutting edge of the technology.

The role of intellectual property rights (IPRs) is important in influencing investments and technology transfer across countries. Of course IPRs are believed to guarantee to foreign companies the expected profits derived from investments made in the host country. As a result, the perception of the strength in the protection of intangible assets is a great determinant in the decision making process before committing itself to large investments in foreign economies. Indeed, multinational companies deciding to bring the product, the knowledge and the technologies in the host countries face several choices that range from export or licensing to the investment in production facilities and in other cases also in R&D facilities. Of course only the physical establishment of the MNE through a subsidiary could affect considerably the possibility of knowledge transfer, for the reasons explained above. There are several factors that influence this critical decision: the first refer to the strength of the IPR system.

A weak IPR regime increases the probability of imitation in the final customer market, thereby eroding what we called previously the "ownership advantage" of multinationals' strategic assets. However, the weak protection might increase the benefit from internationalization, since the positioning of a direct subsidiary in the host country that acts directly in competition with other potential competitors is a safer strategy with respect to licensing to local firms that could breach the contract to free–ride. Maskus (2000) suggested also that IPRs should have a different role and degree of importance in different sectors in terms of encouraging FDI: in fact, investments in low–technology goods and services sector depend less on IPR, while in other sectors investing in new technology that is costly to imitate firms may put a lot of emphasis on the strength of the local legal system.

Other factors deserve to be mentioned like the presence of fiscal and financial incentives to R&D and an effective legal IPR system. The presences of monetary incentives, such as tax incentives and R&D subsidies, have long been discussed in the literature. The performance of these policy instruments, indeed, has not proven to be always successful, since their use has not encouraged efforts in innovation activities.

However, this argument goes beyond the scope of our research and for this reason we do not enter into an in depth discussion of this topic. Turning back to the importance of the national innovation system, it is clear that the availability of excellent research centers, good universities strongly linked to the private sector is a major driver for the establishment of R&D activities in the host economy. Having good and talented scholars, students and researchers is important not only for the development of domestic capabilities in the field of technology, but also to attract and retain talent (Guimón, 2009).

Sometimes R&D projects attract pools of talented researchers that may induce multinational companies to establish their own R&D facilities close to these centers. Amongst the policies that can be used in order to build a strong human capital base, a country could implement tax reduction for high skilled immigrants that work in the host country with purposes of research activities or participation to R&D projects, or by allocating more budgets to universities and research institutions and in the end building appropriate infrastructures such as technology parks and scientific parks. Additionally government should be concerned about the costs of patenting activities, in that difference among countries may be still relevant.

As the literature in national innovation system suggests (Lundvall, 1985), probably the critical point is to strengthen links and collaborative practices between the actors involved in innovation ,research and operating in the economy, in particular fostering the interaction between education, research and public sectors.

A number of studies in the neo–schumpeterian tradition suggest that knowledge diffuses also from the host countries to MNEs affiliates. MNEs affiliates activities abroad are increasing, instead of just utilizing the existing stock of knowledge of the company. Evidence on such flows is given by studies following very diverse approaches: a number of authors have employed, as we have, patent citation data or used patents to compare the technological specialization of the firm and the host country (Cantwell and Piscitello, 2002); others investigated the motives of location decisions of overseas MNEs R&D activity (*e.g.*, Cantwell and Mudambi, 2000) and showed the importance of the scientific and technological specialization of the host country. Studies based on survey data (Molero, 2001) have also confirmed the existence of such flows.

To conclude this section, we argue that in the end internationalization of innovative activities is capable of increasing the performance of the firms, as well as the survival in the increasingly globalized environment: increasing internationalization and shorter product life cycles require the access and the combination of diverse and rare knowledge sources. Multinational companies that go abroad to exploit not only market opportunities, but also a wide pool of knowledge sources, can outperform local companies and those enterprises that, when going multinational, are not able or not willing to absorb new knowledge. Internationalization can also improve the ability to innovate by allowing firms to hire better technologists and access skilled technical expertise. Internationalization is an opportunity also for host countries because of positive spillovers.

1.5. Collaborative R&D and MNEs

After having analyzed in depth what means for a MNE to be international from the innovation point of view, what are the drawbacks and the advantages, the drivers and the barriers to the internationalization of R&D activities and innovation, we now focus on a specific component of this important and comprehensive trend: internationalization.

The internationalization of the group of researchers and inventors that are involved in the recombination and the exploitation of different knowledge sources for the production of innovative products and new knowledge itself play a critical role in the MNE. In this sense, cooperation and inter–organizational linkages among researchers based in different countries is an important and a peculiar aspect that has not yet been fully addressed by scholars in the literature and constitute a new field of research.

The original view of centralized R&D was supported because of several reasons such as the perceived need for a critical mass of researchers to reach economies of scale in the activities, high costs of coordination and communication between geographically dispersed R&D units and an easier way to control property rights on the output of innovative activities (Brockhoff and Schmaul, 1996). However, the pioneering work of Cohen and Levinthal (1989) on the "absorptive capacity" introduced a new vision of how R&D should lead to creation of knowledge and in turn to competitive advantage. And we argue that this theory constitutes an important milestone to understand the theoretical importance of R&D internationalization, both in terms of the creation of knowledge and innovation networks in the global landscape and in terms of internationalization of R&D activities.

The main insight provided by the two scholars is that firms invest in R&D to appreciate, select and utilize the knowledge created elsewhere outside the boundaries of the firms. Indeed, a firm cannot produce alone within its facilities all the knowledge needed to develop innovations and scientific outputs. Opening innovation to other important actors and interacting with them constitutes a much more powerful strategy than retaining and protecting the information and knowledge cumulated, thanks to private R&D investments.

The sources of innovation, then, are often found between firms, universities, research centers, suppliers and customers than inside them (Powell, 1990). Absorbing new knowledge is not the only reason why firms could decide to engage in collaborations and interactions, other reasons may be found as we suggested before obtaining access to new markets and making use of complementary skills in geographically distant territories. In this section we will focus in particular on proactive participation in joint R&D and other technological innovation projects with other organizations.

It is worth noticing , that even if MNEs are in the best position to exploit the potential of connections among international sources of knowledge, the fierce competition and globalization brought about challenges also to small and medium enterprises and the advantages deriving from the access of this typology of firms in the innovation networks can help them to offset the size–related advantages of larger, multinational firms: acquiring knowledge uniquely through big expenses in research activities is no more a unique way to build a competitive advantage.

Indeed, Tether (2002) using UK data on innovating firms, finds that R&D cooperation is mostly the domain of firms pursuing radical innovations rather than incremental innovations. The typology of actors involved in collaborative R&D influences also the outcome of innovation efforts: as witnessed by Belderbos *et al.* (2004), competitor and supplier cooperation focused mainly on incremental innovations, while university cooperation and again competitor cooperation are instrumental in creating and bringing to the market radical innovations.

1.6. Internationalization of inventive activities in MNEs

In the previous section we mostly underlined the causes, the decision models leading to the internationalization and the performance of R&D activities across national boundaries at a firm level. However, in a macro perspective, several phenomena have to be taken into account to study how the process of globalization is affecting the R&D organization during the last decades.

In other words, we did not take into account how the specific features of countries, such as their degree of specialization and the characteristics of their innovation systems, are actually affecting the internationalization of innovative activities. Indeed, the importance of the innovations in each country differs strongly according to their sectoral and technological specialization. Scholars (Porter, 1990) have pointed out that the increasing integration of national economies is parallel to an increasing sectoral specialization in industrial production.

Building on this argument, we argue that an international division of labour might probably be one of the main drivers of international collaborations in inventive and innovative activities. As a result, the more specialized a country is in selected areas, the greater the exchange and cooperation needed with other countries to take advantage of national sectors of strength and to gain access to advanced know how in areas of national weakness (Archibugi and Pianta, 1992).

For this reasons we should expect a greater openness to internationalization from more specialized countries. As witnessed by The Economist (2004), most of the companies see the exploitation of skilled labour as the most critical benefit of globalized R&D. In other words, they tap into one or more of the R&D skills pools that are proliferating around the world and this is a key factor especially in highly innovative sectors. This is also for this reason – amongst many factors like labour costs, quality of local infrastructure, favourable tax regimes and government incentives – that the biggest magnet for R&D globalization is identified to be the skills and competencies intrinsic to each national innovation system. If we extend the considerations of our analysis beyond the private sector, the quality of education system and the presence of excellent research centers are among the most important factors companies look for while establishing collaborations or moving R&D subsidiaries abroad.

However, this openness to collaboration is conditioned by other variables as Picci (2010) showed, demonstrating that the amount of bilateral collaboration is positively affected by determinants that are different from simply the degree of specialization in a certain sector. By using a gravity model for the study of bilateral collaborations in inventive activities, it has been found that geographical distance negatively affects international collaboration.

Whereas having a common border, sharing a common language and having more similar technologies has a significant positive affect on international inventive collaboration. The physical distance could proxy for a cultural distance, meaning that technological advances in communication thanks to information and communication technologies (ICTs) and the myth of the death of distance are not yet in the position to threaten the role of geographical proximity. Again, this finding supports the longstanding dichotomy regarding tacit and codified knowledge, the importance of a close interaction between economic actors and the absence of social and cultural barriers for communication. Consequently, ICTs and the decrease of transport/travel costs contributed to, but did not bring about the growth in international collaborations. Guellec and Van Pottelsberghe (2001), on the basis of a distinction between two main dimensions of internationalization of technology, that is cross–border ownership of technology (for example an invention made in country A is owned by a firm based in country B) and the international generation of knowledge (co–operation between industrial R&D laboratories located in different countries), analysed the trend towards the globalization of innovation in the OECD area and how countries' features affect this phenomenon.

As already commented, an increasing share of technology might be owned by firms in countries where R&D facilities have been established in form of subsidiary, in order to exploit the opportunities offered by closeness to complex consumer markets or to benefit from the access to knowledge intensive areas. This process ends up with cooperation in the invention of new products and technologies. On the other side researchers belonging to different countries that are specialized in certain scientific and technological fields, are able to cooperate for innovation purposes thanks to the rise of global R&D networks. Indeed, the exploitation of these networks is important mostly because of the international division of labour we mentioned before, as specialized expertise can often be available in different countries.

Guellec and Van Pottelsberghe (2001) adopted a country level approach to address some issues we have not been able to delineate before, finding that the higher the GDP, the less a country is open to the international collaboration in innovation in both the dimensions described above. These findings show that smaller countries are more internationalized than larger ones ceteris paribus. On the other hand, R&D intensity has a negative impact on collaboration, meaning that in sectors where the country is not specialized nor sufficient investment levels are reached, the country is more willing to engage in collaborations, because it has weaker capabilities thus it can benefit from knowledge flows from abroad.

The multinational composition of research and inventive groups, as a result of the mushrooming of pools of specialized technologists and scientists all over the world, finds important evidence also in the phenomenon of immigration of skilled labour from developing to advanced countries. This important impact of immigration has not received much attention in the last years, but scholars have started analysing both its direct and indirect effects on innovation performances. As Hunt and Gauthier–Loiselle (2010) witnessed, skilled immigrants could increase patenting activities.

The first reason lays in the fact that they are mostly concentrated in science and engineering occupations that are more easily transferable across countries, because the knowledge required for these activities is less subjected to cultural and communicational barriers. In particular they demonstrated that a one percentage point increase in US immigrant college graduates raises patent per capita by 15%, with immigrants having positive spillovers in S&T activities. This calls for the analysis of the effect of pooling people with diverse backgrounds in particular areas, with people from different nationalities having a positive impact on innovation through the increase of cultural and ethnic diversity. Borjas (1999) argues that immigrants are not randomly selected samples from sending countries. There is a process of self–selection in which the skilled workers who migrate may also be more entrepreneurial and less risk averse (*e.g.*, Kloosterman and Rath, 2003).

Additionally, immigration is very selective of age, with the majority of migrants being young adults in their twenties or thirties. Consequently, immigration slows down ageing of the population and the resulting more youthful workforce may be expected to be more innovative (Poot, 2008). Additionally, the global mobility of highly skilled workers has been increasing sharply due to globalization, the growing importance of the knowledge economy and transfers within transnational corporations (*e.g.*, Poot *et al.*, 2008).

Professional migrants often make multiple moves over the life course or even commute between multiple residences. This mobility behaviour generates spillover benefits to host countries in terms of transfers of new ideas and work practices that may encourage process and product innovations. Another interesting aspect we are going to comment on relates to the fact that immigration can boost innovation generating greater cultural diversity in the host economy. Indeed, even if it has been demonstrated that, internationalization of research and development activities is negatively affected by cultural distance and geographic distance among participants to innovation activities (Picci, 2010), the importance of diversity and the heterogeneity of research teams has been recognized by recent literature to be an important factor in R&D performance.

As has been explained before, MNEs feel the need to absorb and combine different and distant sources of knowledge outside the boundaries of the firm. This way of managing R&D activities could well be reflected in the way companies organize and structure innovation. The MNEs bring together researchers and inventors with different cultural and ethnic background from around the world for knowledge intensive tasks. The negative effects of building up internationally heterogeneous groups may still persist, mainly because diversity is extremely difficult to manage and communication problems are often likely to limit the potential of innovation teams. As a result, the multinational and multicultural groups of researchers and inventors usually perform either exceptionally well or exceptionally badly (Adler and Gundersen, 2008). Despite these drawbacks, very diverse R&D team show some big advantages:

- the possibility of looking at problems to be solved from very different perspectives,
- generating a wide range of solutions and proposals (McLeod et al., 1996), with an enhancement of creativity and superior problem solving skills associated to heterogeneous teams.

The pattern of specialization has led to the establishment of a very diverse national systems, specialized in different fields of industry and technology. Hence, it might be concluded that building a multinational innovation team is a way to collect together complementary skills and thereby benefit from important synergies. Of course diversity can also lead to a greater understanding and sensitivity towards different customers and market segments because different cultures are collected together.

However to benefit from international teams in innovative activities it is important to overcome stereotypes and eliminate communication barriers. Collaboration in research and scientific field deserves a special attention, as researchers are increasingly networked across national borders, organizational borders (OECD, 2011), technological borders and scientific specialization..

As in the case of collaboration in technological field as well, geographical and cultural proximity are known to influence international scientific collaboration. In any case, the widespread uses of the English language, as well as the communication technologies have helped to extend the scope of international research collaboration. Meyer and Bhattacharya (2004) reported interesting findings after having compared scientific and technological collaborations that may help to understand some peculiar characteristics of co–invention activities and collaborative R&D in private industries.

Analyzing two sets, the first collecting scientific publications and the second exclusively patents, the authors found that even if the amount of multi–authors/inventors was high in both sets, the share of individual inventors was seven times higher than the share of individual authors of scientific articles. Moreover the share of collaborations with a small number of participants is much higher in the first data set. This denotes a much weaker tendency to collaborate in inventive activities, also in those that are performed by the most productive inventors in terms of patenting.

Moreover, after mapping the links between co–authors and co–inventors, it has been possible to show that different typologies of collaboration belong to these two communities. Indeed, the authors show a high degree of interconnection while inventors collaborations are mostly dyadic, probably reflecting the “intramural” nature of inventive activities and the tendency to limit knowledge diffusion in order to appropriate the competitive advantage deriving from inventive efforts.

1.7. Conclusions

On the basis of the findings and the suggestions provided by the literature in the economics of innovation, we provided a comprehensive explanation of the phenomenon of R&D globalization. MNEs play a key role in the global transfer of knowledge by absorbing and stimulating innovation activities in host economies.

The increasing technological and sectoral specialization of countries has contributed to the increase of collaboration among nationally diverse economic actors, thereby affecting the way firms manage their innovation activities.

Even if geographical and cultural distance play a crucial role in determining both the willingness and the performance of international inventive groups, we argue that teams that pool researchers and inventors with very different backgrounds constitute one of the next frontiers in the organization of innovation activities.

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Chapter 2
The internationalization of inventive activity: a new index based on cross–country patent data

2.0. Abstract

This chapter discusses extent and dynamics of the internationalization of inventive activity by means of an innovative indicator based on cross–country patent data. The index we propose is designed to measure the degree of geographical heterogeneity of inventors working in a same research group. By applying our index to the European Patent Office (EPO) database, we then conduct a empirical analysis exploring main trends in the internationalization of research groups as resulting from patent applications data going from 1979 to 2008.

While being overall rather low, the observed level of internationalization of inventive activities shows on average to have steadily increased over time. Instead, a negative trend appears when research groups include inventors from BRICS or the Asian Tigers. Moreover, the amount of collaboration between inventors residing in different countries and its trend over time turns out to differ markedly across technology classes.

2.1. Introduction

The recently growing number of studies over the globalization of R&D witnesses a likewise growing interest of scholars in this complex topic. Yet, while the vast majority of them concentrate on issues related to the geographic location of R&D activities with respect to that of company headquarters, little attention has been focused on the geographical internationalization of inventive groups.

Porter (1990) pointed out that the increasing integration of national economies is parallel to an increasing sectoral and technological specialization in industrial production, suggesting that global division of labor is one of the main drivers of international collaborations in inventive activities. Following this theory, the more specialized a country is in a certain industry, the greater the exchange and external cooperation needed by its inventors to acquire diverse knowledge and skills in complementary technological fields.

Developing countries as BRICS and Asian Tigers have seen a spectacular increase in the amount of investments from advanced countries in the last thirty years. These investments are no more directed only to exploit cost advantages, but to extract the outstanding value of knowledge sources provided by the market and by local innovation systems. Skilled human capital, as depository of both tacit and explicit knowledge created and accumulated in different national systems of innovation, is thus a crucial unit of analysis for the investigation of technological patterns in the global landscape.

With respect to such analysis, the study of the international composition of research and inventive groups can unveil the modalities and characteristics of knowledge pooling from a technological and industrial perspective. Aside from international collaborations in R&D activities, the geographic heterogeneity of inventors working in teams and the degree of diversity therein has been recognized to be an important factor of R&D teams' performance important factor of R&D teams' performance (Ancona and Cantwell, 1992).

On the one side, multiethnic and multicultural groups of nationally heterogeneous inventors had proven to be very difficult to manage and communication problems are likely to burden the performance of innovation activities. On the other side, highly diverse R&D teams showed considerable advantages over homogeneous ones, in that the possibility of looking at problems from many different points of view enhances creativity and is often crucial in order to find outstanding solutions in problem solving. Furthermore, the typology of knowledge is likely to influence the extent of communication, since the degree to which knowledge can be codified and its contextual character varies among technological fields.

In this chapter we present a new methodology based on cross–patent data to build an indicator of internationalization of inventors' groups. Such indicator is then used to conduct an explorative empirical analysis over data from the Worldwide Patent

Statistical Database (PATSTAT) that is maintained and distributed by the European Patent Office.

2.2. Literature review

The aim of this chapter is to provide a new indicator for the internationalization of inventive activity, designed to measure the heterogeneity of inventors in the same research group in terms of residence country, on the basis of data over cross–country patents, i.e. patents with multiple inventors from more than one country (Bergek and Bruzelius, 2010).

In order to avoid confusion, we here refer specifically to the internationalization of *inventive activity* and not to that of R&D in general. Previous literature has referred to the internationalization of R&D in an ambiguous way, using the expression to indicate different concepts time by time. As recently clarified by Bergek and Bruzelius (2010), the internationalization of R&D regards "the distribution of R&D activities across national borders" (*ibid.* p:1322). This definition follows the one provided by Archibugi and Coco (2004), who defined international R&D projects as those whose participants were located in more than one country. Such definitions actually suit a plethora of diverse situations and can therefore be misleading.

For instance, we can talk of international R&D in case the development activity is done by a joint venture owned by firms from different countries; otherwise, the same expression can be referred to the research activity jointly conducted by research centers located in different countries but held by the same MNE (Archibugi and Pietrobelli, 2003), or more generally to the establishment of strategic research facilities abroad (Niosi 1999).

These and other cases in which R&D is maintained to be "international" on the basis of the geographical location of physical research facilities and applicants' headquarters, do not imply per se that the *group of inventors* who actually took part in the research project is formed by people from different countries. For example, a MNE owning research facilities abroad could send chief researchers from its home country to direct and coordinate research projects. Since often not all the staff, but only the project chiefs are filed as inventors in patent applications, in a similar case the cross–

border location of R&D facilities (and therefore the internationalization of R&D as previously defined) would not result from an analysis of inventors. The other way around, it is not hard to imagine a case in which we can observe internationalization in a group of inventors without geographical dispersion of R&D facilities. Researchers residing in different countries can end up working together in the same research centre.

The concept of internationalization referred to R&D in general is thus different from the same concept applied to research groups, which is the object of our analysis and to which we here refer as the "internationalization of inventive activity". This stated, we agree with the critiques moved by Bergek and Bruzelius (2010) towards the use of cross–country patent analysis in the assessment of international R&D collaboration. Studying the critical case of ABB, they showed that only the 60% of the company's cross–country patents were actually resulting from international R&D collaboration in its broadest sense[1].

However, the validity of cross–country patents as an indicator of international inventive activity *per se* is not questioned by Bergek and Bruzelius (2010); indeed, they define them a "reasonably good indicator" to that aim (*ibid*, p. 1331). It must be recalled here that in the estimation performance of such indicator they find a marginal upward bias, due to the fact that in 17% of the analyzed patents some inventors moved abroad only after the project had ended, providing the patent office with the new country as that of residence (therefore inflating the extent of estimated international activity). On the other side, it has to be acknowledged as well that many researchers acquire residence in the country where they work. Therefore, inventors who were born, raised and educated in different countries often appear from patent data to have the same nationality, because they all reside in the same country: that in which they all steadily work. This fact evidently biases downwards the degree of internationalization of research groups as estimated through the analysis of cross–country patents.

In the light of the discussion above, we feel safe claiming the validity of our new indicator based on cross–country patent data as an estimator of the extent of internationalization of inventive activity, i.e. of geographical heterogeneity among

[1] Including patents resulting from both inter–subsidiary and inter–firm collaboration.

inventors in research groups. Unlike the large majority of previous studies providing cross–country patent indicators (see Guellec and van Pottelsberghe de la Potterie, 2001; Picci, 2010; Montobbio and Sterzi, 2013), we here deliberately choose to completely disregard the topics of geographical difference in the location of R&D activities and applicant headquarters, as well as international R&D collaboration among firms in general, in order to focus on the geographical composition of research groups.

Although these topics are highly interdependent and their joint study is likely to be necessary in the quest for a comprehensive theory over the globalization of R&D, our aim here is just to provide a new methodological tool for the investigation of the internationalization of inventors' groups.

The importance of such investigation is brought to evidence by a number of recent studies hereby reviewed. As stated by Montobbio and Sterzi (2013, p. 3), "co–inventorship can be used as a proxy of knowledge flows generated by interpersonal and social links deriving from the collaboration in the inventive project".

According to them, the analysis of co–invention can be used in particular to track flows of non–codified (or tacit) knowledge, which need face–to–face interactions in order to be effective. The usefulness of studying co–invention to investigate knowledge flows is witnessed also by Singh (2005), who shows the existence of an inverse relationship between social distance of inventors and the probability of knowledge flow. In that study, inventors' networks were drawn indeed on the basis of co–signed patents.

Again, Breschi and Lissoni (2001, 2009) find knowledge diffusion to be determined both by inventors' mobility and their co–invention network. All these results imply that by studying the internationalization of research groups, one should be able to obtain a picture of knowledge flows across countries.

This explains why so much effort has been put in looking for indicators of the internationalization of inventive activity based on cross–country patents. Guellec and van Pottelsberghe de la Potterie (2001) measured the degree of international research co–operation *for a single country* as its share of patents involving at least an inventor from a different country. They found that the average index for OECD countries more than doubled in fifteen years, raising from 2.1% in 1980 to 4.7% in 1995.

Moreover, they showed that smaller countries in terms of GDP were more internationalized in inventive activities and that the R&D intensity of a country was inversely related to the internationalization of inventive groups in which it participated: low R&D intensity and small countries rely more on external cooperation due to their weaker capabilities, thus benefiting from knowledge flows from abroad.

However, despite being a fair indicator for the country–level extent of internationalization in inventive activity, the index developed by Guellec and van Pottelsberghe de la Potterie (2001) completely disregards the internationalization degree of single inventors' groups.

Using the principle of fractional counting (which assigns to each country a proportion of patent equal to the proportion of its residents among the patent's inventors), Picci (2010) provides instead an index that measures the strength of the relation between inventors from two different countries working in a same research group.

This index can be computed per patent or in an aggregate fashion and it is equal to the product of the proportions of patent assigned to the two countries. As such, it measures the intensity of a dyadic relationship and it was designed this way to be used as dependent variable in a gravity model.

By means of this model, the author found that the amount of bilateral collaborations is positively affected by the presence of a common language, a common border and by more similar cultural features, while it is negatively affected by distance.

The index developed by Picci (2010), although applicable to single inventors' groups (unlike that of Guellec and van Pottelsberghe de la Potterie, 2001) and suitable for determining the collaboration extent in inventive activities of two countries, is not able to provide a measure of internationalization of the research group itself. In fact, none of the studies in this research field provides a similar measure to our knowledge.

As better explained in the next paragraph, our unit of analysis here is the research group defined as the set of inventors of a single patent and our attention is focused on its degree of internationalization (not on that of inventive activity of a single country, nor on the inventive co–operation among two countries); therefore, we are here looking for a measure of the geographical heterogeneity characterizing inventors in the same research group.

2.3. Measuring the internationalization of inventors' groups

As already said, in this chapter we analyze trends in the internationalization characterizing groups of inventors who were granted a patent by the EPO between 1979 and 2008. The group of inventors working on a patent is what we call a research group.

Research groups have a variable number of inventors and for each of them, patent offices record the country of residence in a file with other personal information. We are here interested in investigating the rate of internationalization within research groups, that is, the *extent* of heterogeneity in terms of residence country of their components. In order to measure this extent, we need an indicator with specific features.

First of all, we think the best way to describe the extent of something is by means of a rate going from 0 to 1. In our case, such a rate needs to be minimum if every inventor in the group comes from the same country, while it has to be maximum in case each of them comes from a different one. To measure the alleged degree of heterogeneity we propose to use the complementary function of a normalized Herfindahl–Hirschman index (HHI).

To our knowledge this is the first time such an index is proposed and used for this purpose. Let us take a close look at it. In our case, a simple (not normalized) HH index would be computed as:

$$HHI = \sum_{i=1}^{n} (q_i)^2 \tag{1}$$

where n is the number of different countries *of residence* of inventors in the observed research group and q_i is the share of inventors in the group residing in country i. For instance, if we had a research group composed by three inventors, two of which were German and one Italian, we would have: $n = 2$, with $q_{Germany} = 2/3 = 0.66$ and $q_{Italy} = 1/3 = 0.33$. The resulting HHI would be the sum of the squares of these two numbers (0.54). Such an index would measure geographic *homogeneity*[2] of inventors (the extent to which they come from a same country) and it would range from $1/n$ to 1, so it would not constitute a rate in a proper sense. Moreover, groups with a different n cannot be compared by using this index.

Consider for example two research groups: one in which there are two inventors coming respectively from US and Japan and a second one in which there are three investors from Brazil, Canada and Denmark respectively. Now, it is clear at first sight that the concentration extent in the two groups should be the same (namely, the minimum), since in both of them each inventor is from a different nation. Still, the HHI for the first research group would be equal to 0.5, while that for the second one would be equal to 0.33. This is due to the fact that, as said, the lower bound of the HHI is inversely related to n and shifting from one value of n to another generates differences in the minimum value of the HHI. Furthermore, given a same difference between the values of n, the induced difference in the minimum value of the HHI will be higher the lower the two n are in absolute value. This means that the problem of incomparability is more serious for little values of n.

With respect to this, the average number of inventors in a group in our sample (highly representative of the EPO patents population) was of 2.61, with a standard deviation of 1.94, reason why this problem appears to be quite severe.

In order to overcome the issue of comparability, we decided to use a normalized HHI. The formula to calculate the normalized HHI is the following:

[2] Often *homogeneity* is referred to as the opposite concept of *concentration*. Therefore, assessing that an index of concentration (as the HHI is) measures homogeneity could move to some critics. However, concentration and homogeneity are here referred to two different subjects. As a matter of fact, in our context the concentration *of the group* in terms of residence country of its components corresponds to the homogeneity *of inventors* in the same terms.

where N is the number of inventors in the research group and HHI is the simple Herfindahl–Hirschman index as computed in equation (1). This index ranges from 0 to 1, independently of n. Going back to the example above, both the observed research groups would now show an H^* equal to 0. The one described in equation (2) is a standardized indicator of geographical homogeneity of research groups.

$$H^* = \frac{N \times HHI - 1}{N - 1} \tag{2}$$

Now, in order to obtain our indicator of *heterogeneity*, we simply compute the complementary fraction of H^*, subtracting it from 1, as computed in equation (3). We call our indicator the index of Inventors' Group Internationalization (IGI) and formally define it as follows.

$$IGI = 1 - H^* = 1 - \frac{N \times HHI - 1}{N - 1} \tag{3}$$

This indicator measures the internationalization of a research group on a range going from 0 to 1, being 0 in the case all inventors reside in the same country and 1 in that each of them reside in a different one. As stated in our literature review, contrarily to all previous indexes based on cross–country patents, the IGI provides a measure of internationalization of the research group itself, adding a dimension to the set of variables describing a patent.

Moreover, being a normalized measure, it allows for the comparison of groups (and therefore of patents) with a different number of inventors. This means that, in a patent dataset, each patent will show its own IGI score and will be comparable with all other patents on the basis of such score. We believe that these features of our index will render possible a number of new analyses over patents and we start hereby an explorative investigation of IGI over empirical data collected from the EPO dataset.

2.4. Empirical analysis

2.4.1. Data

The empirical part of this study builds upon a subset of a larger dataset constructed and maintained by CRIOS Bocconi. We take advantage of a unique source of firm–level innovation data derived from European patent records. Data processing consisted mainly in a thorough work of cleaning and standardization of rough information provided by the EPO. The dataset includes all patent applications from the European Patent Office (EPO), from January 1st 1979 to December 31th 2008, which makes our time span the longest analyzed in literature to this moment. It comprises 2,340,200 patents and it includes the full set of bibliographic variables concerning each patent application, namely:

- priority, application and publication number;
- priority dates, application and grant date;
- title and abstract;
- designated states for protection;
- main OST30 class;
- applicant's name and address;
- inventors' names and addresses.

The European Patent Office (EPO) grants European patents for the contracting states to the European Patent Convention (EPC), which was signed in Munich on October 5th 1973 and entered into force on October 7th 1977. All patent data were procured from the EPO and elaborated by CRIOS. In particular, bibliographic data on patent applications are derived from the Espace Bulletin CD–R produced by the EPO, while information on patent citations come from the REFI tape also provided by the EPO.

2.4.2. General findings

Once computed the IGI for each patent in our dataset, we divided the patents by their year of priority and obtained the average IGI for each year. This way we were able to describe the general trend in the internationalization of research groups for EPO patents from 1979 to 2008. Figure 1 below shows this trend.

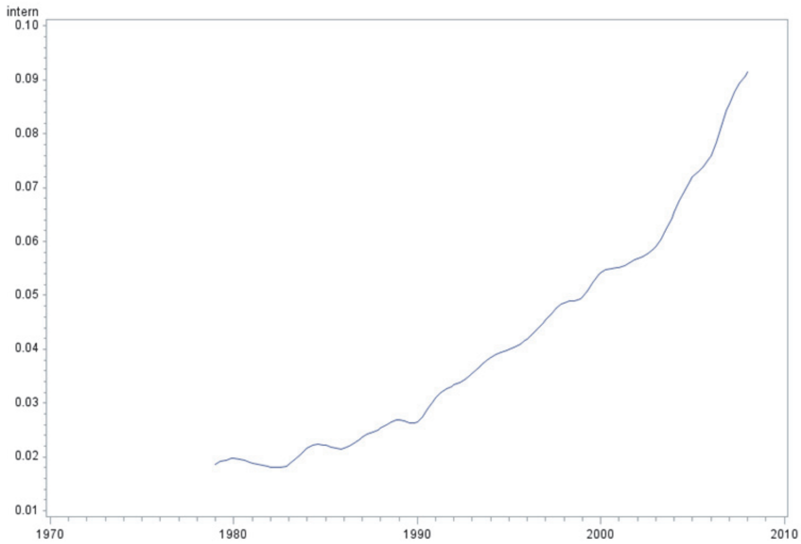

Figure 1 – Average yearly IGI index for EPO patents

According to the figure, the IGI evidently follows a pretty defined increasing path over the whole period. From an average level of nearly 0.018 in 1979, it rises to over 0.09 in 2007. Considering that the scale goes from 0 to 1, such levels could be judged to be extremely low at a first sight. Although this is true, it must be considered that many of the observed patents had only one inventor, which means they had an IGI equal to 0.

These patents deflated the level of the index, but such effect did not have an impact on the shape of the line. As a matter of fact, this latter remained almost identical after a second computation of the index run by omitting patents with a single inventor (reason why we do not report this second graph here).

A noteworthy change after such different computation was instead that the IGI level increased to 0.06 in 1979 and to more or less 0.14 in 2008, resulting in an even stronger positive trend. Two general considerations can be done by looking at this first raw description of data.

First, there is a clear tendency towards the internationalization of research groups which patented inventions in Europe in the last thirty years. An increase in the average IGI of such groups entails a tendency for them to be composed by inventors always more heterogeneous in terms of residence country. This trend towards internationalization has followed an almost exponential path, growing the index by more than four times in thirty years; without experiencing sharp discontinuities during the observed time span.

Second, according both to the original computation of IGI and to the one not considering patents with a single inventor, the average index level was generally quite low. In both cases it never outreached the 0.15 threshold, which means that, despite the observed trend towards internationalization, geographical homogeneity of inventors still characterizes the large majority of research groups. Such results are in line with those found by Picci (2010) and Guellec and van Pottelsberghe de la Potterie (2001).

In order to gain a more thorough insight on this phenomenon, we decided to split our sample in subsamples, grouping inventors' residence countries in four different clusters: OECD countries, BRICS countries, Asian Tigers and Others. As known, OECD includes 34 countries often referred to as "developed", while BRICS is an acronym for Brazil, Russia, India, China and South Africa, all developing countries with a large population which experienced a high GDP growth in the first decade of this century. "Asian Tigers" instead is the name under which we here group the Asian South–East emerging economies (both the traditional four and the minor four): Taiwan, South Korea, Singapore, Hong Kong, Malaysia, Indonesia, Thailand and Philippines. South Korea is actually belonging also to the OECD group, but this does not raise issues with respect to our analysis.

Countries composing the "Others" group are developing or underdeveloped ones with a very low number of inventors in our dataset, therefore we decided to exclude them from the following investigation. From now on, we will refer to OECD, BRICS and Asian Tigers by the term "development macro–areas".

Figure 2 describes the trend of the average IGI index computed by taking into account patents with inventors resident in OECD countries only. This subsample actually included almost the totality of patents from the original sample, counting 2,169,172 patents.

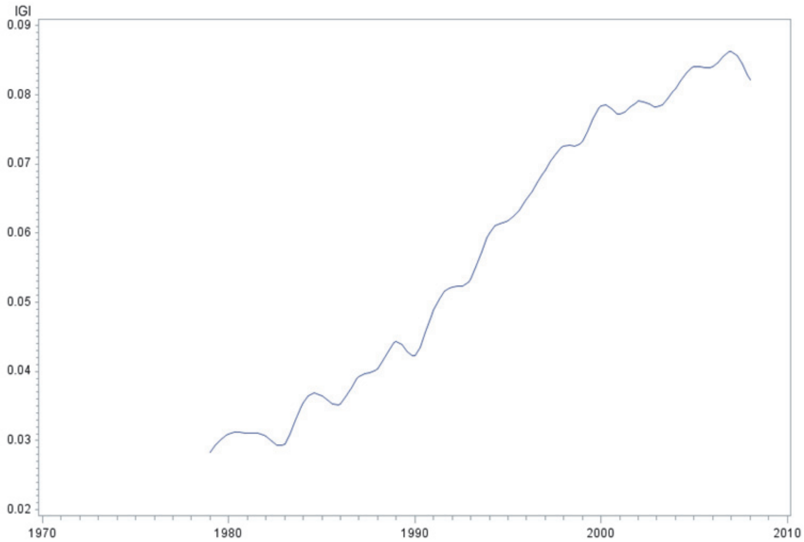

Figure 2 – Average yearly IGI index for EPO patents with OECD inventors only. Pry stands for Priority Year.

That is why the path followed by the index resembles closely the one showed in figure 1, even if with some differences. We observe again a clear trend towards the internationalization of research groups, although this trend is now less smooth, with many noticeable variations throughout the period.

The initial level is here a bit higher than that measured over the total sample, as it lies right under 0.03 instead of 0.02 in 1979. On the other side, the index computed over OECD inventor groups shows a minor decline in the last year of our time span, ending its walk slightly above 0.08 (instead of a 0.09 total IGI).

Moreover, the sharpest rise of internationalization is observable over the '90s in figure 2. As a matter of fact, from a 0.04 level in 1990, the index doubled in ten years, growing to 0.08 in 2000.

The IGI computed over the whole sample showed instead its sharpest rise in the next decade, climbing from 0.054 in 2000 to 0.092 in 2008, while in the same years the OECD IGI registered an overall negligible growth (from 0.078 in 2000 to

0.083 in 2008). Therefore, although a common growing trend, OECD research groups experienced a decreasing growth *rate* in the last twenty years of analysis, while for the sample as a whole this rate was increasing.

Beyond that of OECD groups of inventors, we computed the yearly average IGI also of research groups composed *only* by inventors from BRICS countries and the same was done with Asian Tigers. However, these two subsamples were immeasurably inferior in size with respect to the first one: the “only BRICS” subset counted 22,518 patents, while the “only Asian Tigers” one was made by 45,444 ones.

Moreover, research groups from these two subsamples started to have a significantly constant presence in our dataset only since the early Nineties. Before then, we have a consistent lack of patents whose inventors are *only* from BRICS or *only* from the Asian Tigers.

This brought the average IGI computed on such subgroups to be extremely volatile from year to year, reason why we do not report it here. Instead, we analyze below the average yearly IGI computed on research groups containing *at least one* inventor from BRICS and the same index for those with *at least one* inventor from the Asian Tigers.

Also these two subsamples were highly undersized with respect to the total sample (31,787 patents with at least one inventor from BRICS and 51,022 with at least one from Asian Tigers) and here as well the trend is not reliable before the early Nineties.

However, we decided to report here the IGI scores for such groups since their path after that point in time is particularly interesting. Such scores are reported in figures 3 and 4 below.

Consistently with what stated above, before the early Nineties the trend is highly variable year by year in both graphs. As said, this is due to the small number of research groups in this period within these subsamples.

However, from 1994 on, both subsamples show at least 145 inventors’ groups per year, a number that grows over time to almost 2000 for BRICS and 3000 for the Asian Tigers in 2008. This allows us to safely make some considerations over the trend showed by the IGI index in the second half of the observed time span. First of all, research groups with at least one member coming from a BRICS country always maintained higher levels of internationalization both if compared to the total sample and to the OECD sample.

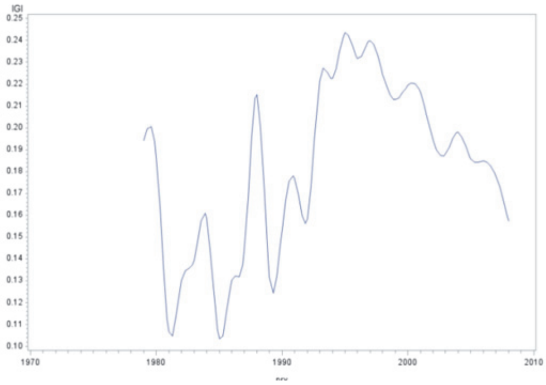

Figure 4 – Average IGI index for EPO patents with at least one inventor from BRICS.

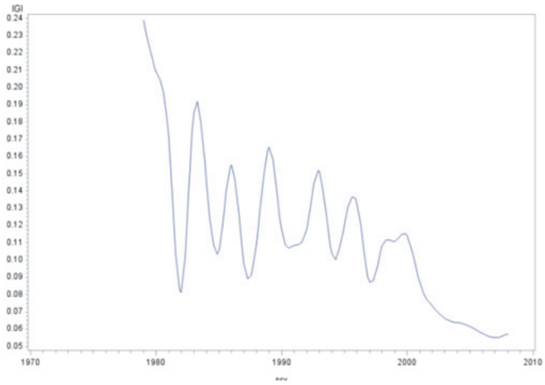

Figure 3 – Average IGI index for EPO patents with at least one inventor from the Asian Tigers.

As a matter of fact, the lowest value showed by the IGI in the left graph of figure 3 lies around 0.1 and it is not even in the reliable part of the graph. In the last 15 years, the lowest value was around 0.15, with a peak of about 0.24 in 1995. Groups of inventors with at least one person from the Asian Tigers registered instead IGI values that ranged from 0.15 to around 0.06 in the reliable interval.

Second, even if decreasing over time, the volatility of the two trends in figure 3 remains pretty high if compared to figures 1 and 2. Third and most important, despite the noticeable volatility both the trends are decreasing from a certain point in time. Namely, after reaching a peak of internationalization in 1995, research groups comprising BRICS inventors started to experience a severe decline in the index. On the other side, for groups with at least one inventor from the Asian Tigers, the same index showed a cyclical path during the '90s preceding a more stable decline from 2000 on. These declining trends in internationalization could be due to the fact that all the countries composing the two analyzed development macro–areas experienced a strong GDP growth during the observed time span. Guellec and van Pottelsberghe de la Potterie (2001) found that less developed countries tend to have more internationalized research groups, partly because researchers in these countries have fewer local colleagues and need therefore to cooperate with foreigners. Such result is consistent with the higher *levels* of IGI we found in groups with at least one inventor from BRICS or from the Asian Tigers, compared to OECD countries. If GDP is negatively related to the internationalization of research groups, then it seems reasonable that economies with a high and sustained GDP growth will experience a decline in the level of internationalization.

In the end, we tried to assess the degree of internationalization of groups no more in terms of countries but in terms of development macro–areas. To pursue this aim we computed again the IGI in a different fashion: in equation (1) we substituted n with the number of different *macro–areas* (instead of countries) of residence of inventors in the observed research group and q_i with the share of inventors in the group residing in *macro–area* i. The resulting indicator, that we will call IGI_macro, measures the degree to which research groups are composed by inventors from different development macro–areas.

Figure 5 shows the yearly average IGI_macro computed on our sample. Although its level turns out to be overall very low (the index ranges from 0.0025 to 0.023), the heterogeneity of inventors in terms of macro–area of residence clearly increased during the observed time span. This result witnesses an increase of the co–operation in inventive activities among developed and developing countries as well as between different groups of developing countries (namely, BRICS and Asian Tigers). Following Montobbio and Sterzi (2013), we hypothesize that this can be due, among other causes, to an increase in trade between macro–areas and to an increase in their technological proximity.

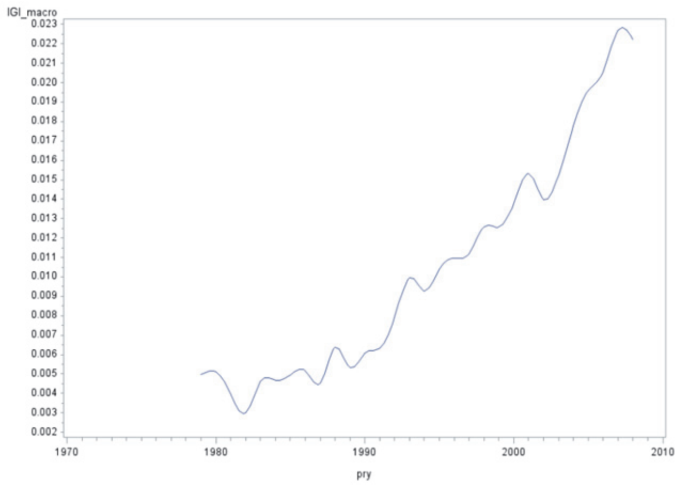

Figure 5 – Average IGI_macro index for EPO patents.

2.4.3. Trends by technological family

2.4.3.1.Trends in IGI

In order to gain a more accurate view over this phenomenon, we decided to investigate whether specific groups of patents followed the general trend exposed in figure 1 more closely than others. In particular, we were interested in understanding if the technological class to which patents belonged had an effect over the internationalization trend of research groups. As a matter of fact, it could be the case for some technological fields to be more resistant than others to such process, for example due to the nature of their knowledge base or of their research networks. In general, if the knowledge necessary to innovate in a given technological field is highly tacit, localized and country– or culture–specific, it is natural to assume that research groups in such field will show an internationalization rate lower than the average. Also, the research networks characterizing some technological fields are more close to the academic environment than others and this could generate differences in the internationalization of research groups. These of course are only a couple of the possible explanations for different trends of internationalization in different technological fields, but the search for such explanations goes beyond the scope of this article.

To appreciate differences in the IGI index among technological fields, we divided patents in our dataset according to the OST30 classification. This categorization (elaborated by Fraunhofer Gesellschaft – ISI (Karlsruhe), INPI – Paris and OST – Paris) sorts patents in 30 different classes according to their technological field. After dividing EPO patent files in these classes we computed the average IGI for each class by splitting the observed time span in three 10–years long periods: 1979–1988, 1989–1998, 1999–2008.

This way we obtained three scatter plots showing the average IGI index for each OST30 class over each decade observed. Such procedure provided us with three consecutive pictures of the concentration level in each patent class, helping us spot how the internationalization process evolved differently among different technological families within the thirty years observed. Such scatter plots are shown in figure 6 below, while descriptions for the OST30 classes are provided in appendix 1. These average scores were computed excluding patents issued by a single inventor to avoid distortions. Even if OST30 is actually a categorical variable, we decided to plot it according to its values.

This because OST30 classes are ordered and clustered in six macro classes: Electrical Engineering (classes 1 to 5), Instruments (6 to 9), Chemistry and Pharmaceutical (10 to 17), Process Engineering and Special Equipment (18 to 22), Mechanical Engineering and Machinery (23 to 28) and Consumption (29, 30). The scale is the same for all the three plots to help comparison.

From the plots below a strong clusterization of OST30 groups in terms of average IGI is increasingly evident over time. Overall, we can notice that classes tend to shift towards the right as time goes by. Such shift is sharper between the second and the third decade than between the first two ones.

This entails an overall acceleration of the internationalization process over time, confirming the almost exponential trend seen in figure 1. Looking closely at the behavior of specific clusters, we notice that while on the one side electrical engineering, mechanical engineering and instruments clusters tend to lag behind in the process, on the other side the chemistry and pharmaceutical cluster clearly shows to lead it with classes 17 (Materials, Metallurgy) and 12 (Pharmaceutical, Cosmetics) scoring the highest average IGI in the last decade (about 0.17 and 0.16). In the end, Process Engineering and Consumption always show internationalization values near the average.

In order to better appreciate differences in the dynamics of the process, we calculated the annual average IGI for each class as well. Again, this index was computed disregarding patents with sinlgle inventors to avoid biases. This way we were able to observe a much more detailed description of the trend in concentration experienced by each technological class. We do not report here the graphics for a matter of space, but we provide track of the main facts.

The first thing we notice is that, despite the general trend spotted by figure 1, not all OST30 classes show to have actually experienced it. Classes 22 (Environmental technology) and 28 (Space technology and weapons) in particular, after a number of consistent variations both downwards and upwards, ended the period with a substantially unchanged (and very low) IGI. A minor increase in the index was then shown by classes 23 (Machine tools) and 24 (Engines, Pumps turbines), beyond 26 (Mechanical elements) and 27 (Transport), which kept their average IGI almost unvaried if we disregard the last three years.

Moreover, if we split the observed period in three ten–year spans and estimate the first derivative of a simple regression of the time series (also not shown for matter of space), we notice that the tendency is not always monotonically positive over the thirty years. Namely, there are some classes which even showed a negative trendency in the first decade. These are classes: 3, 5, 6, 8, 14, 20, 24, 26, 27, 28, 30. Such classes all belong to those which showed a low average IGI in the three plots composing figure 6 and the only one of them which belongs to the chemical and pharmaceutical technological cluster is class 14 (Agriculture and Food chemistry).

Despite such initial slight decrease during the Eighties, all these classes turned towards a positive tendency in internationalization during the two subsequent decades. Furthermore, almost all of them showed a steeper slope as time went by, accellerating their path. In general, the great majority of classes experienced such an acceleration between the second and the third decade, as we saw in figure 6.

Only Information technology and space technology and wepons classes showed a deceleration in the tendency towards internationalization (as noticed, the latter has in fact an almost horizontal trend). In the end, all classes saw their average IGI increase in the last two decades.

Summarizing, we find that pharmaceutical and chemical technological fields experienced overall a higher and faster internationalization of research groups over the period compared to other technological fields. This could be due to the fact that research in such fields is often brought about by large MNEs and university spin–offs, both being high–powered centers of attraction for researchers worldwide. Beyond being

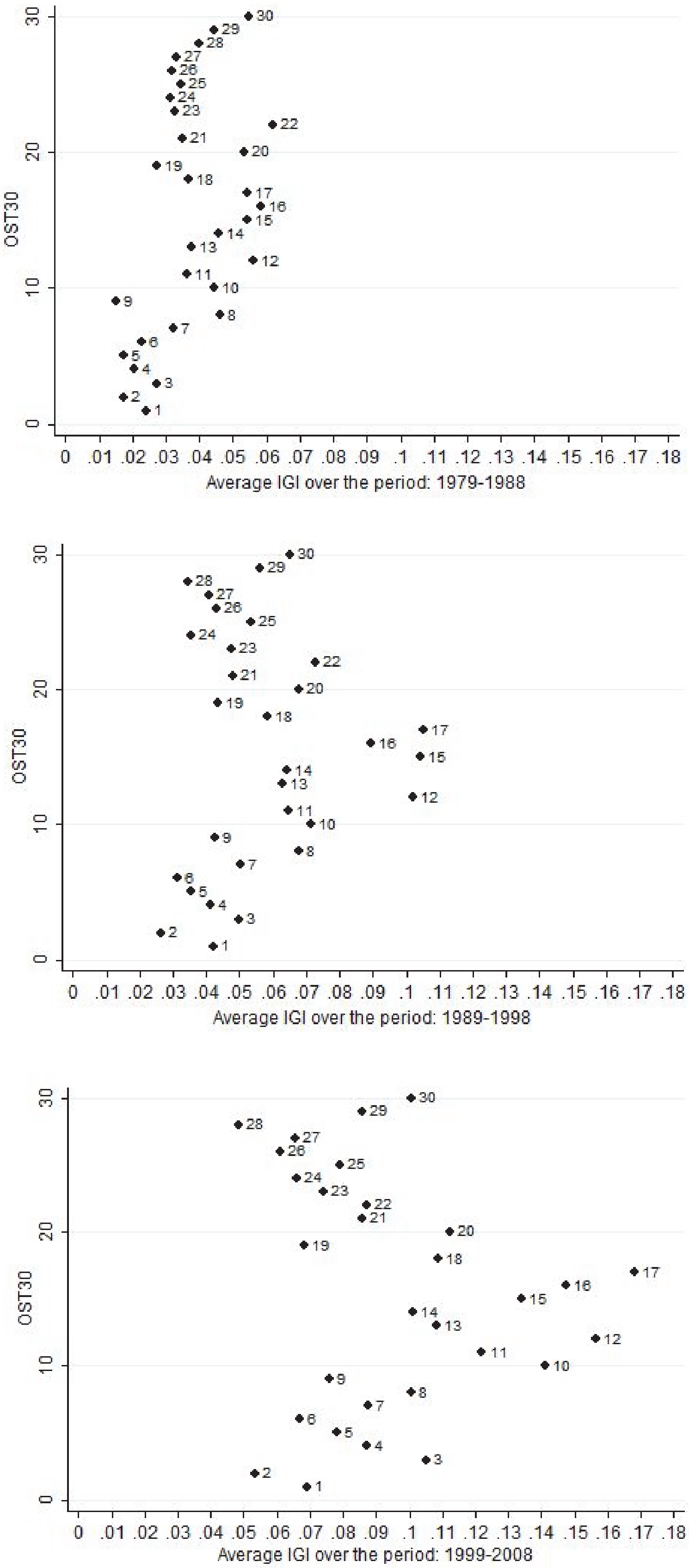

Figure 6 – Ten–year average IGI scores for each OST30 patent class.

in line with results by Guellec and van Pottelsberghe de la Potterie (2001), our finding could actually be a cause for those results. As a matter of fact, by analyzing *industrial sectors* (not technological fields) over the period 1993–1995, they found that chemicals, oil refining, drugs and food and beverages were the most internationalized, while shipbuilding and aerospace were the least ones.

Although they underline their results are supported by Dunning and Wymbs (1999), who show that the pharmaceutical sector relies more than others on foreign sources to gain competitive advantage, while the aerospace one does the opposite, they do not speculate over the causes of such findings.

We here suggest that the different degrees of internationalization found by Guellec and van Pottelsberghe de la Potterie (2001) among industries are likely to be determined by the (increasingly) different extent of internationalization in technological fields resulting from our analysis. Obviously, to prove this causality would require a much more thorough analysis, which however outranges the scope of the present study.

2.4.2.2. Trends in IGI_macro

To conclude our empirical analysis of research groups' internationalization by technological field, we here present the results obtained by observing OST30 classes internationalization in terms of development macro–areas. To do so, we simply plot IGI_macro average scores for all the classes over the three decades, as did before with the simple IGI. Results are shown in figure 7. The overall level of co–operation in inventive activity across development macro–areas is extremely low for all classes, as resulting also from figure 5.

However, we see again a trend towards heterogeneity in research groups and a tendency of technological families to clusterize over time in macro classes. As before, the fastest in this process are classes related to the chemical and pharmaceutical industries. Beyond reaching higher levels of IGI_macro in the last period, these classes lie way ahead the mean also in the middle decade, when all other classes barely start to intake a similar path towards heterogeneity. This entails that pharmaceutical and chemical research groups not only increasingly tend to

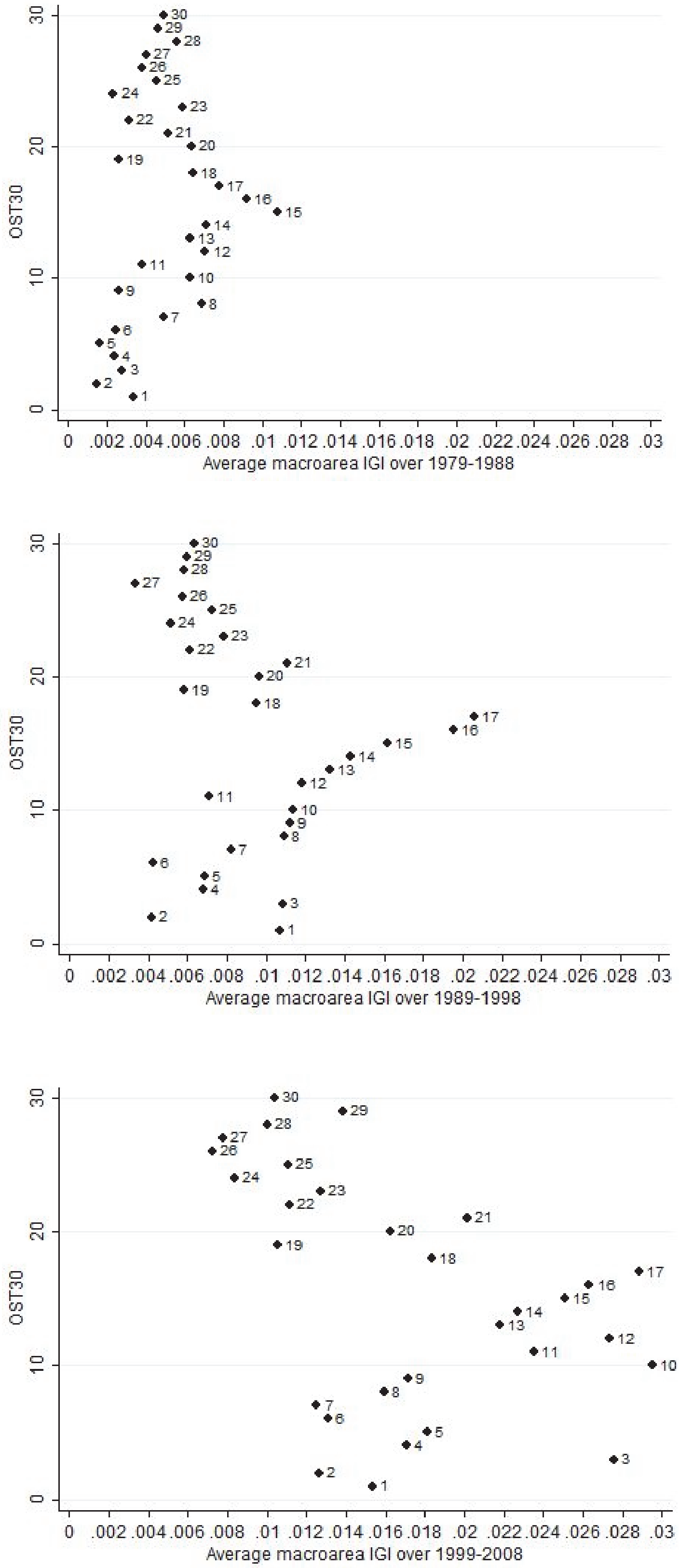

Figure 7 – Ten–year average IGI_macro scores for each OST30 patent class.

be more internationalized than others, but they rely more and more on inventive co–operation between developed and developing countries.

To conclude, the situation in figure 6 is in general confirmed also after aggregating countries in development macro–areas. The only noticeable exception is represented by class 3 (Telecommunications), which shows a shocking growth in its average IGI_macro during the last decade. Remembering from figure 6 that this class experienced an overall internationalization trend perfectly in the average, this second result make us suggest that a large part of its internationalization happened among countries from different macro–areas in the last decade. All the findings exposed above are quite relevant to our opinion, since they surely help shape the general process of internationalization more in detail.

2.5. Conclusion

The aims of this chapter were mainly two. Firstly, it was meant to provide our methodological contribution to the research strand investigating the internationalization of knowledge production and diffusion. This was made by proposing the use of a new index to estimate the degree of internationalization of patent inventors' groups. Secondly, by applying the computation of such index to a wide panel dataset containing all patents granted by the EPO from 1979 to 2008, we tried to spot the main tendencies in the internationalization of research groups over this period. We perform the analysis at first at a general level, then dividing patents according to the presence of inventors from BRICS and from the Asian Tigers and further to their technological class.

At a general level, a clear and almost exponential increase of internationalization in inventors' groups was found over the whole observed period. This means that an overall trend towards geographical heterogeneity of inventors in such groups has taken shape. However, the average level of this heterogeneity was always quite low, the total IGI never rising over 0.15. A similar result was shown by OECD research groups, while in the case at least one inventor from BRICS or from the Asian Tigers appeared in the group, our internationalization index showed a decreasing path. After providing such general descriptions of the phenomenon, we also verified that its intensity (and its very presence) varies across technological sectors. Electronic Engineering, Instruments and Mechanical Engineering patents show on average more geographical homogeneity in groups of inventors, while chemical and pharmaceutical technologies are more likely to be generated by more heterogeneous research groups.

Similar results are observed when analyzing internationalization in terms of development macro–areas, with the exception of telecommunications technologies, for which inventive co–operation among macro–areas appear to be a major driver of internationalization in the last decade.

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2.7. Appendix I: Description of OST30 classes.

OST30	Description
1	Electrical machinery and apparatus, electrical energy
2	Audio-visual technology
3	Telecommunication
4	Information technology
5	Semiconductors
6	Optics
7	Analysis, measurement, control technology
8	Medical technology
9	Nuclear engineering
10	Organic fine chemistry
11	Macromolecular chemistry, polymers
12	Pharmaceuticals, cosmetics
13	Biotechnology
14	Agriculture, food chemistry
15	Chemical and petrol industry, basic materials chemistry
16	Surface technology, coating
17	Materials, metallurgy
18	Chemical engineering
19	Materials processing, textiles, paper
20	Handling, printing
21	Agricultural and food processing, machinery and apparatus
22	Environmental technology
23	Machine tools
24	Engines, pumps, turbines
25	Thermal processes and apparatus
26	Mechanical elements
27	Transport
28	Space technology, weapons
29	Consumer goods and equipment
30	Civil engineering, building, mining

Chapter 3 Internationalized innovative activities in multinational enterprises: a geographic and sectoral analysis

3.0. Abstract

In this chapter we describe internationalization trends in innovation with respect to four important sectors: Automotives, Pharmaceuticals, Telecommunications and Semiconductors. For each of these sectors, we picked up the top five MNEs and applied four new indicators that help in understanding the degree of internationalization present in each of the selected MNEs by examining at the geographical nationality of the inventors, the degree of technology specialization of each MNE, the degree of the general purpose of a technology used by MNE, the degree of the general purpose of a technology used by MNE.

While calculating the indexes we have considered the structural changes experienced by the MNEs. This approach helps in understanding the internationalization of innovation whilst simultaneously shedding light on the changes in the organizational structure of the MNEs.

3.1. Introduction

Prior research on MNEs using patent data has generally taken the ownership and affiliate structure of a firm as constituted in a single year and simply assigned patents to parent companies assuming no changes in this structure over time (Cantwell 1995, Patel and Pavitt 1991). Such an approach ignores arising from mergers, acquisitions and dispositions.

This is likely to lead to serious problems in the assignment of patents to parent companies, especially in the late 1980s when many large cross–border acquisitions took place. To ensure that affiliate patents were allocated properly to the parent company, we traced the timing of mergers, acquisitions and dispositions from 1984 to 2003 for each of the MNE.

The sector chosen were: Automotives, Pharmaceuticals, Telecommunications and Semiconductors. For each of these sectors we picked up the first five MNEs in the Fortune Global 500 charts for the year 2004.

Sources used in this tracing process included both electronic and print media such as Who Owns Whom (from 1984 till 2003) and The Directory of International Affiliates (various years). Acquired firms were classified as part of a parent company when the parent had obtained a controlling interest (i.e., a > 50% equity stake).

The aim of the chapter is to provide an analysis of MNEs' characteristics in terms of internalization and other particular aspects of their research activity using a subset of a larger dataset constructed and maintained by CRIOS Bocconi. The data set all patent applications to the European Patent Office (EPO), from June 1^{st} 1978 to December 31^{th} 2008. It comprises a total of 2,492,768 patents and it includes the full set of bibliographic variables concerning each patent application.

Rank	Group Name
PHARMACEUTICALS	
1	**Pfizer (PF)**
2	**Johnson & Johnson (JJ)**
3	**GlaxoSmithKline (GX)**
4	**Novartis (NV)**
5	**Roche Group (RH)**
AUTOMOTIVES	
1	**General Motors (GM)**
2	**Ford Motor (FM)**
3	**DaimlerChrysler (DC)**
4	**Toyota Motor (TM)**
5	**Volkswagen (VW)**
SEMICONDUCTORS	
1	**IBM (IB)**
2	**Toshiba (TB)**
3	**Intel (IN)**
4	**STMicroelectronics (ST)**
5	**Infineon Technologies (IF)**
TELECOMMUNICATIONS	
1	**Nippon Tel. & Tel. (NT)**
2	**Verizon Communications (VZ)**
3	**Deutsche Telekom (DT)**
4	**Vodafone (VF)**
5	**France Télécom (FT)**

3.2. Sectors

3.2.1. Automotives

Automotive manufacturing has evolved into one of the largest industries in the world but prior to the mid–1980s, the U.S. auto industry did not used to engage in many cooperative activities. General Motors, Ford, Chrysler and American Motors had very few links with each other, confining their modest collaboration efforts to Europe and Japan (*e.g.*, American Motors–Renault, GM–Isuzu, Chrysler–Mitsubishi, Ford–Mazda).

The second half of the 1980s featured the beginnings of "Big Three" technological interactions, as well as the rapid expansion of automobile alliances in other developed countries (Hagedoorn 1995, p. 224).

Some of the emergences of collaboration in the U.S. auto industry were a result of much more advanced networking in Japan. By the early 1980s, companies like Nissan, Toyota and Mitsubishi moved aggressively into strategic alliances with other manufacturers, including many non–Japanese ones. The central dynamic of these inter–firm alliances was self–organizational and it provided substantial competitive advantage for Japanese network members, who tended to outpace their international competitor in gaining experience at learning by interacting with other network members (Bowonder and Miyake, 1992).

The automotive industry is one of the most important sectors in terms of total R&D expenditures (UNCTAD 2005, ACEA 2010), even if in this sector R&D was less internationalized than any other industrial sector by the mid–1990s (Dunning and Wymbs 1999; Gerybadze and Reger 1999). Despite rapidly growing automobile production in less developed countries, the largest automotive MNEs conducted about three–quarters of automotive R&D in their home countries in the 1990s, with the rest being located predominantly in other developed economies (Gerybadze and Reger 1999; Zander 1999; Miller 1994).

The automotive sector is a clear example of demand–driven R&D internationalization, with high degree of concentration of part of the inventive efforts related to standardized elements of products and a decentralized R&D sites involved in national and regional adaptation of products to satisfy local consumers' preferences at best. After 1990s automotive companies adopted a successful platform strategy that allowed them to exploit economies of scale by sharing common platforms, basically the chassis and general modules, between different models. These standardized parts (lower bodies) account for about 80 percent of the whole vehicle.

The research and development connected to the production of these cars' subsystems R&D concerning platforms remained concentrated in the home–country of automotive lead firms. On the other side, regional R&D centers specialized in modifications of cars' upper bodies have been established in the most important regional markets (Miller 1994).

This strategy is a clear example of HBE R&D, in that basing R&D facilities close to consumer market facilitates the absorption of information and knowledge that clearly differentiates a market from another. Furthermore on the basis of the Japanese experience, in these last decades carmakers have increased collaboration in innovation activities, with leading firms engaging in co–design and co–inventions with their most important suppliers. Suppliers accounted for about 40 percent of the total automotive industry's R&D in the early 2000s and their share was predicted to increase to 60 percent by 2010 (International Labour Organization 2005). However, according to Dannenberg and Burgard (2007), the suppliers' share of automotive R&D was already 61 percent between 2001 and 2005, twice that of lead firms' (31 percent), while engineering service providers accounted for the remaining 8 percent (Pavlinek, 2012).

The strengthening of cooperation between automotive companies brought about several important consequences. First of all the willingness to engage in co–inventive activities has induced suppliers to establish R&D and production facilities close to the ones belonging to leading firms in order to benefit from knowledge spillovers and to exploit the advantages provided by geographical proximity.

The importance of tacit knowledge for the technological transfer has played an important role. Along with it proximity has helped in reducing time to market and to build trust for long term market relationships. In this perspective, regional innovation systems and technological clustering play an important role for development in the automotive sector, given that a big portion of R&D activities is performed in conditions of geographical proximity with groups of specialized suppliers.

The last important consequence is related to the fact that suppliers residing in regional territories can benefit from the acquisition of the best practices and technologies already adopted by leading carmakers. These transfers are motivated by the fact that car producers are interested in having long term relationships with advanced commercial partners.

3.2.2. Pharmaceuticals

The pharmaceutical industry, especially in recent past, is the prime example of an industry where companies with fairly sophisticated R&D divisions or specialized R&D firms can undertake research for specific drug lines (*e.g.*, Gambardella, 1995; Malerba and Orsenigo, 2002).

The pharmaceutical industry has experienced dramatic changes in the last thirty years. The advances in biological sciences and the emergence of biotechnology clearly represent the first engine of this revolution. Starting from the discovery of the structure of DNA and the development of genetic engineering techniques, the ability to understand the mechanisms of action of drugs and the biochemical and molecular roots of many diseases increased enormously. This has created new opportunities for drug therapy for firms in pharmaceutical industry.

Pharmaceutical sector is one of the sectors mostly affected by the internationalization trend in R&D activities. Pharmaceutical companies are naturally directed to the international market because the nature of the activities in this sector is inherently global for several reasons.

Firstly we are referring to a science driven sector and all the activities that are performed in R&D labs in pharmaceutical companies cannot be performed without the presence of a strong link with the international scientific community, the global network of research institutes and universities.

Furthermore, from a merely commercial point of view, a pharmaceutical company is often forced to sell products to a big mass of customers: the enormous costs of R&D performed within the boundaries of the firm requires the companies to reach a high number of final costumers and therefore, the need to be present on multiple national markets. In the last decades the pharmaceutical sector has experienced an important shift in the organizational paradigm concerning R&D activities. These companies used to organize inventive activities in a very centralized way, in order to benefit from the important possibilities offered by the exploitation of economies of scale and scope.

In the recent past, companies have recognized that the likelihood of producing all the necessary substances to be marketed is generally very low and the reasoning applies also for the biggest companies in the sector, that account only for small percentage of all the R&D conducted globally in this field. This belief and the acceptance of the importance of opening up the gates to external sources of innovation has led to a shift to a new paradigm that puts emphasis on the importance of external sources of innovation.

The sector has seen a huge increase in networked innovation activities, with the rise of a complex net that links companies with complementary assets and even the most important companies' source more than the 50% of their R&D on a global scale.

The drivers of globalization, indeed, are not represented by labour costs or other cost–related motivations but firstly to exploit the possibility of cooperation with other important actors which leads to decrease in factors like, the high risk that characterizes drug discovery, access to new technologies and the new know how.

The market for technology is very active, also thanks to the presence of very small firms all over the world that don't have the possibility or the skills to market pharmaceutical products on their own and for this reason they usually transfer the technology through licensing agreements to big firms. In that way big pharmaceuticals, can access new sources of knowledge and technology without incurring the costs and risks connected to R&D activities.

Other drivers of globalization in the sector are motivated by the need to operate in proximity to foreign markets: protectionists, legal and cultural constraints often require companies to establish R&D facilities abroad (Gassmann and Reepmeyer, 2005). In other cases, companies have been forced to leave the home–country because of legal restrictions, as in the case of European biotech firms that have been forced to move to US.

3.2.3. Semiconductors

The semiconductor industry is often cited as a "strategic" industry in part because important learning–by–doing spillovers may justify special industrial policies (Irwin and Klenow, 1995). By sustaining the growth of the whole microelectronics industry, the semiconductor market has a multiplier effect on several downstream sectors where electronic content is central.

Whether microelectronics have deeply contributed to the success of a wide range of products ranging from electronics systems to communication services, the booming demand for those products, mainly fuelled by new markets in the East, is expected to further drive the evolution of semiconductor technologies and to influence the geography and structural dynamics of the industry.

Historically, the industry's growth has been led by a continuously growing sophisticated demand and a never–ending technological progress. Huge R&D investments and the extensive use of capital have enhanced innovation also beyond the industry's boundaries.

Concentrated or dispersed industrial structures have evolved according to the changes in demand and technology. More recently, along with the growth of developing economies, firms have been moving upstream activities closer to the new markets.

The fragmentation of the industry value chain has evolved along more internationalized borders. Globalization processes related to product development in semiconductor industry started in the early 1960's, when multinational companies started expanding sales, manufacturing and operations overseas.

However, the internationalization of R&D activities started in the 1980's with the outsourcing of R&D efforts to Asian regions. This process and the formation of R&D networks has proved to be very productive as a combination of different regions in the world and their technological strengths utilized for R&D yielded to rapid innovation rates and fewer errors in product development. To explain how the semiconductor industry has been affected by internationalization process it is worth describing the most important activities of the industry's supply chain. The most important element of production is the chip, an integrated circuit based on transistor technology.

For the development and the manufacturing of chips three different activities are required: the design, the production and finally the test and assembly that are usually conducted together. The economic characteristics of the activities differ significantly since design is skill intensive and requires expensive software and specialized design engineers, on the other side fabrication requires lower skills but a huge fixed investment for the plant (brown linden). Finally, the assembly is less costly, even though in this case quite expensive investments are required and no particular skills are needed. The outsourcing of these activities started with assembly and now part of manufacturing is also outsourced.

In addition to this, U.S. multinationals are now increasingly relying on external partners for designing new products. Foreign locations of innovation activities are gaining importance when compared to the other phases of product development. Furthermore, foreign locations are gaining importance despite the high level of automation and the decreasing advantages of labour cost. Indeed the primary reasons why semiconductor companies are internationalizing their value chain activities are the access to location specific resources, such as engineering talent, local market development and access and finally cost reductions.

Countries have become increasingly specialized and skilled in precise phases of the value chain: for example Britain has developed expertise in consumer multimedia and Scandinavian countries are famous for the development of wireless technologies. Nonetheless outsourcing inventive activities, apart from having proved to be a successful strategy, has its costs and threats.

Coordinating amongst Asian subcontractors is difficult, especially when the IPRs cannot be enforced strictly. Indeed, with few exceptions, real world value of patent protection is not very useful either for excluding imitator or for capturing loyalties in most industries (Henkel and von Hippel, 2005).

Furthermore, increasing the amount of work outsourced means relying on subcontractors to discover cost–reducing and quality–improving innovations, activities that were formerly controlled within the buyer's own firm (Lin; Tsai 2007). As a result, the knowledge accumulated by Asian companies due to continuous learning by doing is on the rise.

The rising accumulation of knowledge by the suppliers and the weak IPR regime points towards the cautions the MNEs need to exercise while taking long term decision. In order to survive the global competition, western semiconductor companies are forced to invest continuously in core technologies for devices' production to maintain the competitive advantage and bargaining power with respect to subcontractors.

3.2.4. Telecommunications

The changes in the telecommunications sector in the 1984–1995 period are best described as revolutionary and the causes for this can be identified (Brakman *et al.*, 1995) in the technological innovations, in the growing number of multinationals, which has led to an increase in the demand of cheap global telecommunications networks. These changes have been accompanied by other policy related changes like, an ideological wave of free market competition, liberalization, privatization and deregulation (see also Li and Xu, 2004) that have changed the telecommunications sector.

As for the technological innovations, which are responsible for the radical changes in the telecommunications sector, Estabrooks (1995) distinguishes them in telegraphy, telephony, wireless radio, television, computer satellite communications and cellular communications. However, an account of the total number of innovations is disputable due to many smaller innovations, resulting from convergence of computers telecommunications, cable television, banking and financial services, consumer electronics, publishing, motion picture and entertainment industries. This convergence of many sectors has led to the creation of a heterogeneous network which meets all the information and communications related needs of individuals, homes and business.

Telecommunications is a core sector of the modern manufacturing industry. The impact of development in the Telecommunications can be felt in other industries as well via ICT. Indeed Bresnahan and Trajtenberg (1995) classified ICT as a general purpose technology affecting productivity in almost all sectors. In the case of ICT sector, R&D collaborations and partnership in a global context and thus the internationalization of inventive activities are motivated by several reasons. First of all, ICT is a particularly pervasive sector that has been characterized by an increasing technological convergence, in that the inter–operability of products has made the nature of innovation more and more systematic with time, forcing the firms operating in that industry to collaborate and reshape their business models. Teece (1992) defines R&D collaborations as a specific form of collaborations: “a bilateral relationship characterized by the commitment of two or more partner firms to reach a common goal, which entails the pooling of specialized knowledge and capabilities”.

Indeed, the ICT sector internationalization is not demand–driven, as in the case of the automotive sector we reported above, but appears to be driven by technological convergence that is pushing firms to pool their specialized knowledge and assets to innovate. Palmberg and Martikainen (2006) while analyzing the distribution of R&D collaborative agreements over time found that initiatives undertaken by EU in the coordination of R&D related alliances through programs that encouraged alliances in inventive efforts and at a global level, the development of Internet Protocol in 1990s has seen the peak in the number of collaborations.

The introductions of some important but complex technological standards, such as the GPRS or the UMTS, have probably led firms to engage in fewer but larger alliances. Some observations can be made regarding the amount of FDIs, with India emerging as the most preferred location for R&D, followed by USA and then China. The presence of US as one of the most preferred countries signals the possibility that FDIs in the ICT field may be “asset augmenting”, since they are directed to absorb knowledge in one of the most technologically advanced countries. The total amount of FDIs in India went from just US 2 million in 1993 to US 19 billion on 2009 (UNESCO, 2010) , with lots of investments directed to the Bangalore cluster.

The Indian case is a successful example of policies which have been designed and implemented in order to encourage the absorption of knowledge and support the rise of national system of innovation. Furthermore, the government has continuously sustained R&D expenses and research that transformed an area previously attractive only for labour cost advantages due to the labour intensive character of the old ICT sector into one of the most innovative clusters.

3.3. Indicators

Due to the high complexity related to the sectors and dynamics of MNEs it could be useful considering data on patents in order to analyse R&D characteristics. The main aim of the introduction of indexes based on patents' data is to produce simple measures of specific dynamics that could be used as proxies for determined phenomena.

3.3.1. Index of Inventors' Group Internationalization (IGI)

This is an index of heterogeneity within groups of researchers, in terms of geographical origin of their members at a country level, as explained in chapter 2. Such a rate will be minimum if every inventor in the group comes from the same country, while it will be maximum incase each of them comes from a different one. To measure this heterogeneity extent we use a normalized Herfindahl–Hirschman index (HHI). The formula to calculate the normalized HHI is the following:

$$\mathrm{H}^{*} = \frac{\mathrm{N} \cdot \mathrm{HHI} - 1}{\mathrm{N} - 1}$$

Where, N is the number of inventors in the research group and HHI is the simple Herfindahl–Hirschman index. HHI is the squared sum of the shares of inventors in the group coming from each different country in the considered patent. This index ranges from 0 to 1, independently of the number of different nationalities of patent's inventors. IGI is then calculated as $IGI = 1 - \frac{\mathrm{N} \cdot \mathrm{HHI} - 1}{\mathrm{N} - 1}$

3.3.2. Index of Technological Specialization for MNEs (ISTEM)

This is an index of concentration of the patents granted to a multinational company in a given year in terms of technological class. Its purpose is to provide, for every year of observation, an approximation of the extent to which a single multinational company technologically specialized its inventive activities. A high level of concentration of the technological classes in which the firm patented would entail that such firm specialized its R&D activities in a narrow technological field. In order to measure the technological specialization extent, differently from all the other indicators presented in this chapter, the ISTEM is calculated at firm level and not at patent level.

Each patent in the dataset can be assigned to more than one technological class (OST30 classes), according to the technological fields in which it can be used. For example, a patented molecule suitable for the production of a new drug could be attributed both to class 15 (Chemical and Petrol industry) and to class 12 (Pharmaceuticals, Cosmetics). Taken the whole patent portfolio of a company, the index is the sum of the squared proportion of the number of attributions to a determined class over the total number of attributions of the company in the considered year.

$$ISTEM_{b,t} = \sum_{c=1}^{k} \left(\frac{\#\, patents\ of\ class\ c\ in\ year\ t}{total\ of\ attribution\ for\ b\ in\ year\ t}\right)^2$$

The ISTEM decreases as the number of classes increases and as patents become more diversified in terms of classes. On the contrary, it will increase if one or few classes are predominant on the rest in the firm's annual set of granted patents. The maximum value of this index will be reached in case all the patents granted to the observed multinational company in a given year are assigned to the same OST30 class. On the contrary, it will reach its minimum value if the multinational company presents an equal number of patents in each technological class in which it patented.

3.3.3. Index of Utilization Specificity of Patents (ISUB)

Each patent is assigned more than one IPC (International Patent Classification) class. This proposed index measures the concentration of four–digit IPC macro–classes of each patent, that is, how narrow the scope of use of such patent is. Formally, it is computed this way:

$$ISUB_b = \sum_{c=1}^{k} (p_c)^2$$

Where b is a specific patent, c is a four–digit IPC macro–class, k is the number of four–digit IPC macro–classes to which the patent was attributed and p_c is the proportion of macro–class c over all the classes attributed to that patent. For example the patent 1037159 was attributed to the 8 IPC classes: G06K7/00, G06K17/00, G06K19/077, H01R12/18, H04M1/02, H04M1/2745, H04M1/275, H04Q7/32. Aggregating the classes to a four digit level, we obtain that the patent belongs to 3 G06K classes, one H01R class, 3 H04M classes and one H04Q class. Therefore, $p_{\mathrm{G06K}} = 3/8$, $p_{\mathrm{H01R}} = 1/8$, $p_{\mathrm{H04M}} = 3/8$ e $p_{\mathrm{H04Q}} = 1/8$. The squared sum of all the p provides the ISUB of patent 1037159. This indicator, as much as other concentration indexes, will be at most equal to one, in the event that the patent has been assigned to a single four–digits IPC class and at least $1/k$, in case it has been attributed to an equal number of classes for each four–digit IPC macro–class (given the fact that these are more than one).

The ISUB can be seen as an inverse index of the general purpose degree of a technology. A high ISUB will be attributed to an invention which finds most of its use in a small part of the technological classes to which it is assigned, or – in the extreme case – which belongs only to one class. On the other hand, a low value of this index will be scored by patents with a general purpose, i.e. that are equally belonging to different technological classes. An annual average ISUB can be calculated for companies as well by aggregating patents at the company level. The resulting index will approximate ISTEM indicator of observed firms.

3.3.4. Index of Technological Complexity of Patents (ICTEB)

The Index of Technological Complexity of Patents is also based on an index of concentration. Every patent cites other patents which its technology relies on. Each one of these patents is assigned to more OST30 classes, which indicate its membership to a number of determined technological families.

The ICTEB of a patent is an index of diversity of the patents it cited in terms of OST30 classes. The degree of diversity in the technological classes of patents cited by one patent can be used as a proxy for its complexity. By complexity, we here mean the need to resort to the knowledge embodied in more technological classes in order to generate the concerned patented invention. A patent with ICTEB=0 will have a low complexity in the sense that its own achievement will require the knowledge embedded in only one technological class. Formally, this index is calculated by the following:

$$ICTEB_b = 1 - \sum_{c=1}^{k} (p_c)^2$$

Where c is a OST30 class, k is the total number of OST30 classes to which the patents cited by b belong, and:

$$p_c = \frac{cited\ patents\ belonging\ to\ c}{cited\ patents}.$$

The highest possible value of this indicator is 1–1/k. According to what stated above, a patent with such an ICTEB will be defined as a complex invention, since its creation needed in equal parts the knowledge contained in k different technological fields.

3.4. Results

3.4.1. Index of inventors' group internationalization (IGI)

The inventors' group internalization index as already explained gives us a measure of the degree of internalization of research groups in different sectors or MNE group. While plotting the period of 5 years it is important to consider the distinction between Pharmaceuticals, Semiconductors, Automotives and Telecommunications.

The first two show increasing trends of internalization of their research groups and moreover the highest level of IGI index, while Automotives and Telecommunications have a steady and low IGI. Starting with the automotive sector the most interesting cases are those of GM and Toyota, the previous one exhibits the highest IGI of the sector which is also increasing during the considered time span, the latter is the least internationalized company of the sector.

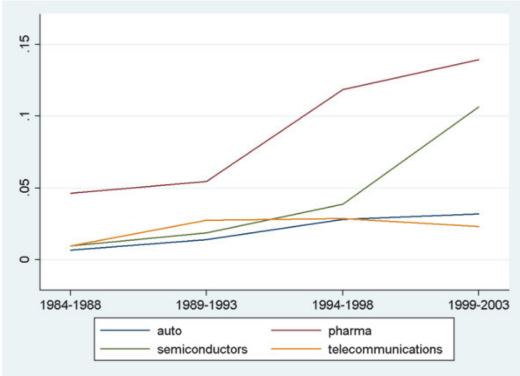

Figure 8 – IGI index calculated for different sectors

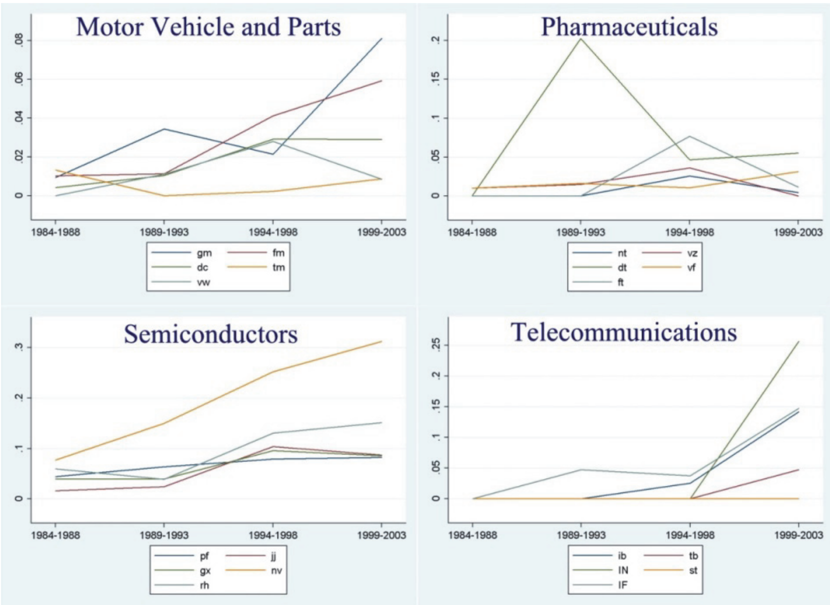

Figure 9 – IGI calculated for each MNE for different sectors

The pharmaceutical sector instead presents similar trends for all the groups except from Novartis which is more internationalized during subsequent periods. In the semiconductor sector two companies draw attention: Toshiba's dramatic IGI increase and the lowest value of the index in the case of STMicroelectronics. Finally, in the telecommunications sector, Deutsche Telekom has a peak during 1989–2003 and then follows the sector's general trend.

3.4.2. Index of Technological Specialization for MNE (ISTEM)

The index of technological specialization for five years suggests that Semiconductors and Telecommunications are the most specialized sectors. Automotive and pharmaceutical sectors on the contrary presents a low level of ISTEM suggesting that patents belonging to their sector could be assigned to a lot of different classes, or that there are no prevalent classes assigned to their patents.

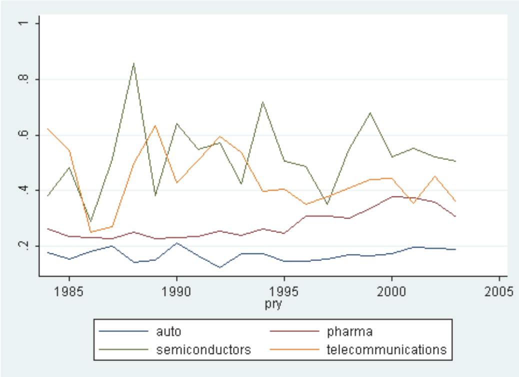

Figure 10 – ISTEM index calculated for different sectors

Annual data show that automotive and telecommunications sectors have an almost steady graph, on the contrary Pharmaceuticals and Semiconductors present many fluctuations through the years.

While analyzing the automotive sector we can highlight the presence of a generalized slightly increasing trend in the last periods except from the case of Toyota which had the highest level of specialization during 1984–1989 but exhibits a decreasing level in the following periods.

In the pharmaceutical sector the Roche case is peculiar because it is the only group that presents a stable tendency during all the considered periods while the other MNEs point towards a growth of the specialization index.

The semiconductor sector on the other hand is characterized by a decline in the last period for all the considered groups with the exception of STMicroelectronics.

Finally, in the telecommunications sector, Vodafone shows a stable and low level of specialization through all the analyzed years and Verizon Communications is the only group that displays a growing ISTEM.

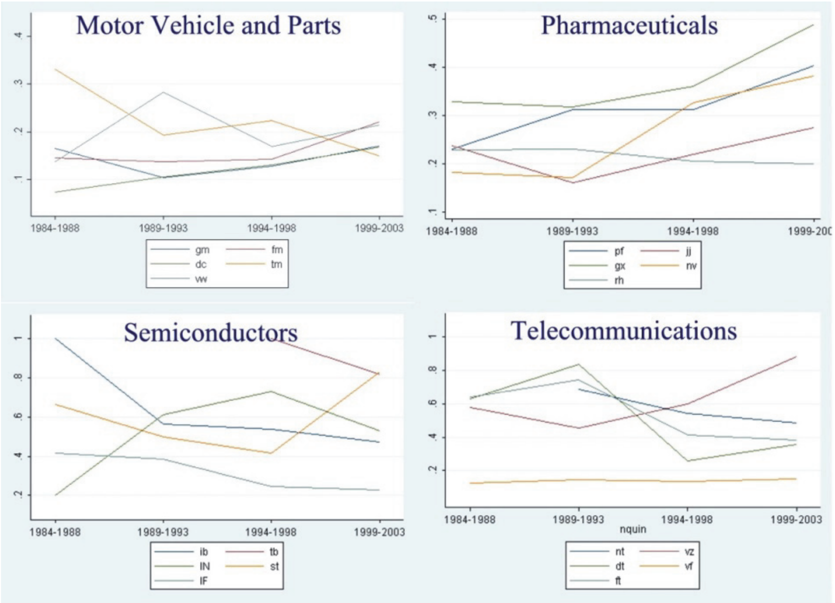

Figure 11 – ISTEM index calculated for each MNE for different sectors

3.4.3. Index of Utilization Specificity of Patents (ISUB)

Looking at ISUB 5 years results it is easy to see that Automotives, Semiconductors and Telecommunications have similar steady trends with values around 0.7/0.8 while pharmaceutical sector is between 0.5 and 0.6 with a lower peak during 1994–1998 period.

From the group analysis of the automotive sector we can identify that all the companies except for Volkswagen have a very similar pattern with decline of the index of utilization specificity of patents in the second and fourth period.

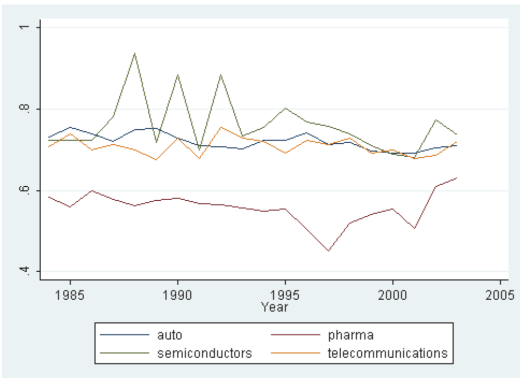

Figure 12 – ISUB index calculated for different sectors

Volkswagen instead has the highest value of this index apart from 1994–1998. During the period of 1994–98 the specificity of Volkswagen's patents increase and this corresponds to a decline in the specificity of its competitor. Switching to pharmaceutical sector, in which 3 companies exhibit an almost steady graph with values around 0.6, the most interesting cases are those of: Johnson&Johnson, the highest in every period and GlaxoSmithKline which has a lower peak in 1994–1998 but then reaches the same level of the other MNEs.

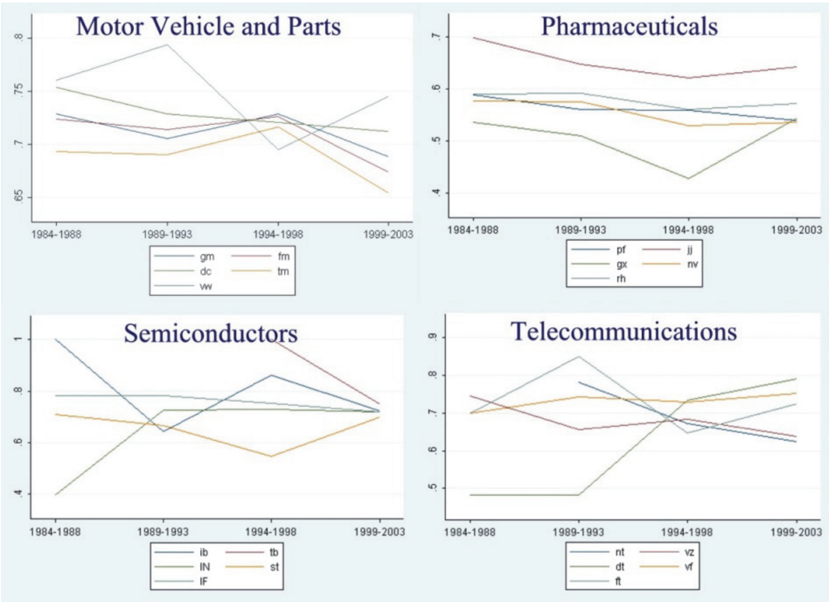

Figure 13 – ISUB calculated for each MNE for different sectors

Finally, semiconductor sector, after the first period in which companies disclose significantly different levels of specificity of patents, during 1999–2003 reaches a value between 0.7 and 0.8. But it is also important to focus on the lack of the ISUB datum for Toshiba and Infineon in certain period.

3.3.4. Indexes of Technological Complexity of Patents (ICTEB)

The value plotted in the graph is the mean of each 5 years period for each sector analyzed. The graph presents a general decreasing trend of the ICTEB index in every sector which, as said before, could be linked both to an increase in asymmetry through classes cited by patents or to a decrease in the number of cited classes.

The most important thing to notice here is that apart from semiconductor sector, which is the one that presents the lowest value of the index in all but one period, the other sectors start at almost the same level in the first period and then evolve differently. Considering the automotive sector it is possible to observe that the most interesting cases are those of: General Motors, which has a steady graph since the last period and then reaches the lowest value among the sector and Toyota Motors which shows a lower initial value than that of GM and a slight decrease in the last period.

The pharmaceutical sector is characterized by the presence of similar values of the index in every period except from the 1994–1998 in which Pfizer and Novartis are outlier with a difference of nearly 0.10 in term of ICTEB from the other groups. The other significant deviation is that of Johnson&Johnson with a value of 0.31.

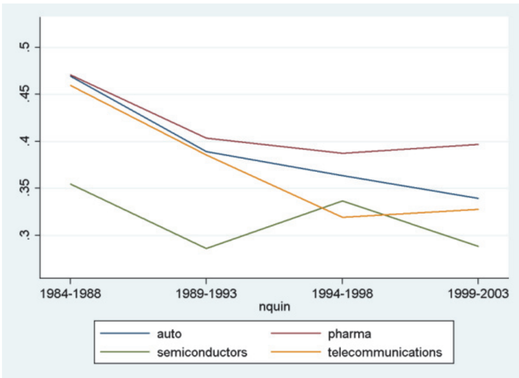

Figure 14 – ICTEB index calculated for different sectors

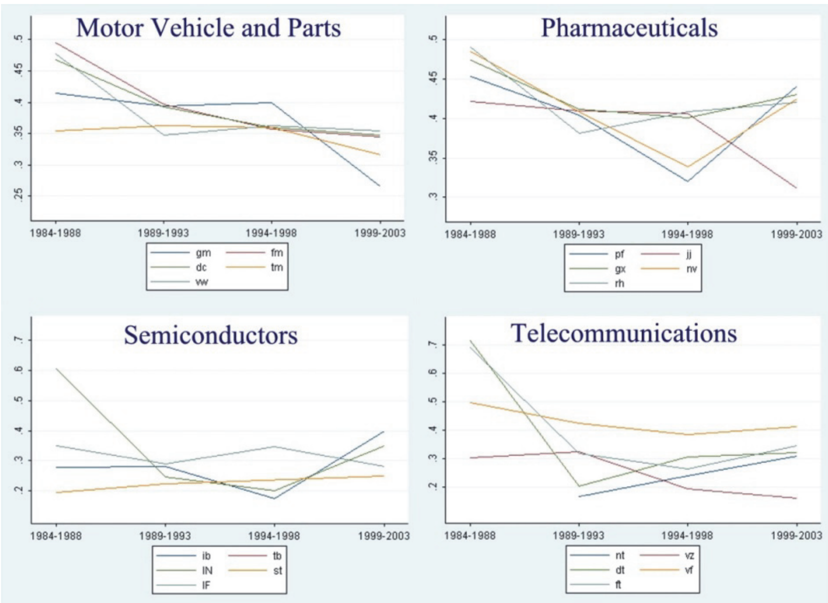

Figure 15 – ICTEB calculated for each MNE for different sectors

3.5. Conclusions

This chapter presents an analysis of the biggest five groups of Automotives, Pharmaceuticals, Semiconductors and Telecommunications. Each group has been considered on the basis of mergers and acquisitions that occur during the considered period, in order to take into account only changes in patenting activity due to MNEs decisions.

This approach, as already remarked, is able to give better results in terms of reliability of results compared with the previous ones which assigned patents to parent companies assuming no structural changes over time. The problems linked to the older approach are based on the intrinsic characteristics of patenting activity which is strategic and could be influenced by changes in the group structure, the approach adopted in this chapter rules out the emergence of such problems.

The dataset of groups has been used to analyse the indexes which have been explained in this chapter. As a result, the indexes help in understanding the MNEs' patent characteristics. The analysis conducted has to be considered as the first step in the study of these indexes, as a matter of fact, it could only highlight some differences between the various groups or sectors. However, it cannot be accounted as sufficient in explaining patents' characteristics or the potential of the proposed indexes. Keeping in mind the limitation the final aim of this chapter is to suggest further investigation of those indexes that could be used to study the features of patenting activity and the relations that eventually could arise with market share or R&D expenditure of a group.

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3.7. Appendix I: Group Composition and Corporate History

3.7.1. General Motors Corporation

General Motors Corporation is a global automaker founded in 1908 with headquarters in Detroit, Michigan. It is the world's second–largest automaker after Toyota, ranked by 2008 global unit sales. GM was the global sales leader for 77 consecutive calendar years from 1931 to 2007. It manufactures cars and trucks in 34 countries. GM employs 244,500 people around the world and sells and services vehicles in some 140 countries. In 2008, 8.35 million GM cars and trucks were sold globally under the following brands: Buick, Cadillac, Chevrolet, GMC, GM Daewoo, Holden, Hummer, Opel, Pontiac, Saab, Saturn, Vauxhall and Wuling.

History and timeline

General Motors was founded on September 27, 1908, in Flint, Michigan, as a holding company for Buick, then controlled by William C. Durant. It acquired Oldsmobile later that year. In 1909 Durant brought in Cadillac, Elmore, Oakland (later known as Pontiac) and several others. In 1909, General Motors acquired the Reliance Motor Truck Company of Owosso, Michigan and the Rapid Automotive Company of Pontiac, Michigan, the predecessors of GMC Truck. Durant lost control of GM in 1910 to a bankers' trust because of the large amount of debt taken on in its acquisitions coupled with a collapse in new vehicle sales. A few years later, Durant started the Chevrolet Motor car company and through this he secretly purchased a controlling interest in GM. Durant took back control of the company after one of the most dramatic proxy wars in American business history. Shortly after, he again lost control, this time for good, after the new vehicle market collapsed. Alfred Sloan was picked to take charge of the corporation and led it to its post war global dominance. This unprecedented growth of GM would last into the early 1980 when it employed 349,000 workers and 150 assembly plants.

Mother company name	*since*	*Till*
General Motors Corporation	1984	2003

3.7.2. Ford Motor Company

The Ford Motor Company is an American multinational corporation and the world's fourth largest automaker based on worldwide vehicle sales, following Toyota, General Motors and Volkswagen. Based in Dearborn, Michigan, a suburb of Detroit, the automaker was founded by Henry Ford and incorporated on June 16, 1903. In addition to the Ford, Lincoln and Mercury brands, Ford also owns Volvo Cars of Sweden and a small stake in Mazda of Japan and Aston Martin of England. Ford's former UK subsidiaries Jaguar and Land Rover were sold to Tata Motors of India in March 2008.

History and timeline

The Ford Motor Company was launched in a converted factory in 1903 with $28,000 in cash from twelve investors, most notably John and Horace Dodge (who would later found their own car company). Henry's first attempt under his name was the Henry Ford Company on November 3, 1901, which later became the Cadillac Motor Company August 22, 1902. During its early years, the company produced just a few cars a day at its factory on Mack Avenue in Detroit, Michigan. Groups of two or three men worked on each car from components made to order by other companies. Henry Ford was 40 years old when he founded the Ford Motor Company, which would go on to become one of the world's largest and most profitable companies, as well as being one to survive the Great Depression. As one of the largest family–controlled companies in the world, the Ford Motor Company has been in continuous family control for over 100 years.

Mother company name	*since*	*Till*
Ford Motor Company	1984	2003

3.7.3. DaimlerChrysler AG

Daimler AG (formerly Daimler–Benz AG, DaimlerChrysler AG) is a German car corporation (not to be confused with the British Daimler Motor Company) and the world's thirteenth largest car manufacturer as well as the largest truck manufacturer in the world. In addition to automobiles, Daimler manufactures trucks and provides financial services through its Daimler Financial Services arm. The company also owns major stakes in aerospace group EADS, high–technology and parent company of the Vodafone McLaren Mercedes racing team McLaren Group and Japanese truck maker Mitsubishi Fuso Truck and Bus Corporation.

DaimlerChrysler was founded in 1998 when Mercedes–Benz manufacturer Daimler–Benz (1926–1998) of Stuttgart, Germany merged with the US–based Chrysler Corporation. The deal created a new entity, DaimlerChrysler.

History and timeline

An Agreement of Mutual Interest was signed on May 1, 1924 between Benz & Cie (founded 1883) of Karl Benz and Daimler Motoren Gesellschaft (founded 1890) of Gottlieb Daimler and Wilhelm Maybach.

Both companies continued to manufacture their separate automobile and internal combustion engine brands until, on June 28, 1926, when Benz & Cie. and Daimler Motoren Gesellschaft AG formally merged—becoming Daimler–Benz AG—and agreed that thereafter, all of the factories would use the brand name of Mercedes–Benz on their automobiles.

In 1998 Daimler–Benz AG "merged" with the American automobile manufacturer Chrysler Corporation and formed DaimlerChrysler AG.

DAIMLERCHRYSLER		
Mother company name	*since*	*till*
Daimler–Benz AG	1984	1998
DaimlerChrysler AG	1998	2003

3.7.4. Toyota Motor Corporation

Toyota Motor Corporation is a multinational corporation headquartered in Japan and is currently the world's largest automaker. Toyota employs approximately 316,000 people worldwide.

History and timeline

Toyota Motor Corporation started in 1933 as a division of Toyoda Automatic Loom Works devoted to the production of automobiles under the direction of the founder's son, Kiichiro Toyoda. It's first vehicles were the A1 passenger car and the

G1 in 1935. Toyota Motor Co. was established as an independent and separate company in 1937.

Mother company name	*since*	*Till*
Toyota Motor Corporation	1984	2003

3.7.5. Volkswagen Group

The Volkswagen Automobile Company, also known as Volkswagen Passenger Cars or just VW, is an automobile manufacturer based in Wolfsburg, Germany and is the original brand within the Volkswagen Group, as well as the largest brand by sales volume

History and timeline

The Volkswagen Group, founded in 1937, contains the car brands Audi AG, Bentley Motors Ltd., Automobiles Bugatti SA, Automobili Lamborghini Holding S.p.A., SEAT, Škoda Auto and heavy goods vehicle manufacturer Scania.

Mother company name	*since*	*Till*
Volkswagen Group	1984	2003

3.7.6. Pfizer Incorporated

Pfizer Incorporated is a pharmaceutical company, ranking number one in sales in the world. The company is based in New York City, with its research headquarters in Groton, Connecticut.

History and timeline

Pfizer was founded in 1849 and is headquartered in New York, New York. By the 1950s, Pfizer was established in Belgium, Brazil, Canada, Cuba, Iran, Mexico, Panama, Puerto Rico, Turkey and the United Kingdom. In 1960, the Company moved its medical research laboratory operations to a new facility in Groton, Connecticut. In 1980 Pfizer launched Feldene (piroxicam), a prescription anti–inflammatory medication that became Pfizer's first product to reach a total of a billion United States dollars in sales. During the 1980s and 1990s Pfizer underwent a period of growth sustained by the discovery and marketing of (Zoloft, Lipitor, Norvasc, Zithromax, Aricept, Diflucan, Viagra). Pfizer has recently grown by mergers, including those with Warner–Lambert (2000) and with Pharmacia (2003).

Mother company name	*since*	*Till*
Pfizer Incorporated	1984	2003

3.7.7. Johnson & Johnson

Johnson & Johnson is a global American pharmaceutical, medical devices and consumer packaged goods manufacturer founded in 1886.

The corporation's headquarters is located in New Brunswick, New Jersey, United States. Its consumer division is located in Skillman, New Jersey. The corporation includes some 250 subsidiary companies with operations in over 57 countries. Its products are sold in over 175 countries.

History and timeline

Johnson & Johnson was founded in 1886. The company has historically been located on the Delaware and Raritan Canal, in New Brunswick. The company considered moving its headquarters out of New Brunswick in the 1960s. Since the 1900s, the company has pursued steady diversification. It added consumer products in the 1920s and created a separate division for surgical products in 1941 which became Ethicon. It expanded into pharmaceuticals with the purchase of McNeil Laboratories, Inc., Cilag and Janssen Pharmaceutica and into women's sanitary products and toiletries in the 1970s and 1980s. In recent years, Johnson & Johnson has expanded into such diverse areas as biopharmaceuticals, orthopaedic devices and Internet publishing. Recently, Johnson & Johnson has purchased Pfizer's Consumer Healthcare department.

Mother company name	*since*	*Till*
Johnson & Johnson	1984	2003

3.7.8. GlaxoSmithKline plc

GlaxoSmithKline plc is a United Kingdom–based pharmaceutical, biological and healthcare company. GSK is the world's second largest pharmaceutical company and a research–based company with a wide portfolio of pharmaceutical products covering anti–infectives, central nervous system, respiratory, gastro–intestinal/metabolic, oncology and vaccines products. It also has a Consumer Healthcare operation comprising leading oral healthcare products, nutritional drinks and over the counter medicines.

History and timeline

In 2000, Glaxo Wellcome and SmithKline Beecham merged to form GlaxoSmithKline.

GlaxoWellcome

Burroughs Wellcome & Company was founded in London in 1880. The Wellcome Tropical Research Laboratories opened in 1902. In 1959 the Wellcome Company bought McDougall & Robertson Inc. to become more active in animal health. The Wellcome Company production centre was moved from New York to North Carolina in 1970 and the following year another research centre was built.

Glaxo was founded in Bunnythorpe, New Zealand in 1904. Originally Glaxo was a baby food manufacturer processing local milk into a baby food by the same name.

Glaxo became Glaxo Laboratories and opened new units in London in 1935. Glaxo Laboratories bought two companies called Joseph Nathan and Allen & Hanburys in 1947 and 1958 respectively. After the Company bought Meyer Laboratories in 1978, it started to play an important role in the US market. In 1983 the American arm Glaxo Inc. moved to Research Triangle Park (US headquarters/research) and Zebulon (US manufacturing) in North Carolina. Burroughs Wellcome and Glaxo merged in 1995 to form GlaxoWellcome. In the same year, GlaxoWellcome opened its Medicine Research Centre in Stevenage. Three years later GlaxoWellcome bought Polfa Poznan Company in Poland.

SmithKline Beecham

Beecham Group was founded in 1843. By the 1960s it was extensively involved in Pharmaceuticals.

Smith Kline & French Laboratories bought Recherche et Industrie Thérapeutiques (Belgium) in 1963 to order to focus on vaccines. The Company started to expand globally buying seven laboratories in Canada and the US in 1969. In 1982, it bought Allergan, a manufacturer of eye and skincare products. The Company merged with Beckman Inc. later that year and then changed its name to SmithKline Beckman.

In 1988, SmithKline Beckman bought its biggest competitor, International Clinical Laboratories and in 1989 merged with Beecham to form SmithKline Beecham plc. The headquarters of the Company were then moved to England. To expand research & development in the US, SmithKline Beecham bought a new research centre in 1995. Another new research centre at New Frontiers Science Park in Harlow was opened in 1997

Mother company name	*since*	*Till*
Burroughs Wellcome	1984	1995
Glaxo Laboratories	1984	1995
SmithKline Beckman	1984	1989
SmithKline Beecham	1989	2000
GlaxoWellcome	1995	2000
GlaxoSmithKline plc	2000	2003

3.7.9. Novartis International AG

Novartis International AG is a multinational pharmaceutical company based in Basel, Switzerland, ranking number one in revenues, which accounted over $53 billion in 2008 and number three in sales, which accounted 36.172 billion in 2008. Novartis is one of the largest healthcare companies in the world and a leading giant among pharmaceutical companies. Novartis manufactures drugs such as clozapine (Clozaril), diclofenac (Voltaren), carbamazepine (Tegretol), valsartan (Diovan), imatinib mesylate (Gleevec / Glivec), cyclosporin A (Neoral / Sandimmun), letrozole (Femara), methylphenidate (Ritalin), terbinafine (Lamisil) and others. Novartis owns Sandoz, a large manufacturer of generic drugs. The company formerly owned the Gerber Products Company, a major infant and baby products producer, but sold it to Nestlé in 2007.

History and timeline

Novartis was created in 1996 from the merger of Ciba–Geigy and Sandoz Laboratories, both Swiss companies with long histories. Ciba–Geigy was formed in 1970 by the merger of J. R. Geigy Ltd (founded in Basel in 1758) and Ciba (founded in Basel in 1859). Combining the histories of the merger partners, the company's effective history spans 250 years

Novartis combined its agricultural division with that of AstraZeneca to create Syngenta in November 2000.

In 2003, Novartis created a new company named Sandoz, a subsidiary that bundles its generic drug production, reusing the predecessor brand.

Mother company name	*since*	*Till*
Ciba–Geigy	1984	1996
Sandoz Laboratories	1984	1996
Novartis International AG	1996	2003

3.7.10. Roche Holding AG

Roche Holding AG is the holding company of F. Hoffmann–La Roche Ltd. that is a Swiss global health–care company that operates worldwide under two divisions: Pharmaceuticals and Diagnostics.

The headquarters are in Basel and the company has many sites around the world – including: Nutley, NJ, Palo Alto, California, Pleasanton, Branchburg, Indianapolis, Indiana and Florence, South Carolina in the US, Welwyn Garden City and Burgess Hill in the UK, Mannheim and Penzberg in Germany and Shanghai in China. The company also owns the American biotechnology company Genentech, which is a wholly owned subsidiary and the Japanese biotechnology company Chugai Pharmaceuticals.

History and timeline

Founded in 1896 by Fritz Hoffmann–La Roche, the company was early on known for producing various vitamin preparations and derivatives. In 1934, it became the first company to mass produce synthetic vitamin C, under the brand name Redoxon. In 1957 it introduced the class of tranquilizers known as benzodiazepines (with Valium and Rohypnol being the best known members). Its acne drug isotretinoin, marketed as Accutane and Roaccutane, also used as a form of chemotherapy for some cancers, has been linked with a number of severe side effects and remains highly controversial but highly effective at the same time. Roche has also produced various HIV tests and antiretroviral drugs. It bought the patents for the polymerase chain reaction technique in 1992. It manufactures and sells several cancer drugs.

In 1982, the United States arm of the company acquired Biomedical Reference Laboratories for US$163.5 million. That company dated from the late 1960s and was located in Burlington, North Carolina. That year Hoffmann–La Roche then merged it with all of its laboratories and incorporated the merged company as Roche Biomedical Laboratories, Inc. in Burlington.

On April 28, 1995 Hoffmann–La Roche sold Roche Biomedical Laboratories, Inc. to National Health Laboratories Holdings Inc. (which then changed its name to Laboratory Corporation of America Holdings). In 1994, Roche acquired Syntex.

Roche		
Mother company name	*since*	*Till*
Roche Holding AG	1984	2003

3.7.11. International Business Machines Corporation

International Business Machines Corporation, abbreviated IBM is a multinational computer technology and IT consulting corporation headquartered in Armonk, New York, United States.

The company is one of the few information technology companies with a continuous history dating back to the 19th century. IBM manufactures and sells computer hardware and software (with a focus on the latter) and offers infrastructure services, hosting services and consulting services in areas ranging from mainframe computers to nanotechnology.

IBM has been well known through most of its recent history as the world's largest computer company and systems integrator. With over 388,000 employees worldwide, IBM is the largest and most profitable information technology employer in the world. IBM holds more patents than any other U.S. based technology company and has eight research laboratories worldwide. The company has scientists, engineers, consultants and sales professionals in over 170 countries. IBM employees have earned three Nobel Prizes, four Turing Awards, five National Medals of Technology and five National Medals of Science. As a chip maker, IBM has been among the Worldwide Top 20 Semiconductor Sales Leaders in past years.

History and timeline

The company which became IBM was founded in 1896 as the Tabulating Machine Company[7] by Herman Hollerith, in Broome County, New York (Endicott, New York or Binghamton, New York), where it still maintains very limited operations. It was incorporated as Computing Tabulating Recording Corporation (CTR) on June 16, 1911 and was listed on the New York Stock Exchange in 1916 by George Winthrop Fairchild. CTR's Canadian and later South American subsidiary was named International Business Machines in 1917 and the whole company took this name in 1924 when Thomas J. Watson took control.

Mother company name	*since*	*Till*
International Business Machines Corporation	1984	2003

3.7.12. Toshiba Corporation

Toshiba Corporation is a Japanese multinational conglomerate manufacturing company, headquartered in Tokyo, Japan. The company's main business is in Infrastructure, Consumer Products and Electronic devices and components.

Toshiba–made semiconductors are among the Worldwide Top 20 Semiconductor Sales Leaders. Toshiba is the world's fifth largest personal computer manufacturer, after Hewlett–Packard and Dell of the U.S., Acer of Taiwan and Lenovo of China.

History and timeline

Toshiba was founded by the merging of two companies in 1939.

One, Tanaka Seizosho (Tanaka Engineering Works), was Japan's first manufacturer of telegraph equipment and was established by Hisashige Tanaka in 1875. In 1904, its name was changed to Shibaura Seisakusho (Shibaura Engineering Works). Through the first part of the 20th century Shibaura Engineering Works became a major manufacturer of heavy electrical machinery as Japan modernized during the Meiji Era and became a world industrial power.

The second company, Hakunetsusha, was established in 1890 and was Japan's first producer of incandescent electric lamps. It diversified into the manufacture of other consumer products and in 1899 was renamed Tokyo Denki (Tokyo Electric).

The merger in 1939 of Shibaura Seisakusho and Tokyo Denki created a new company called Tokyo Shibaura Denki. It was soon nicknamed Toshiba, but it was not until 1978 that the company was officially renamed Toshiba Corporation.

The group expanded strongly, both by internal growth and by acquisitions, buying heavy engineering and primary industry firms in the 1940s and 1950s and then spinning off subsidiaries in the 1970s and beyond. Groups created include Toshiba EMI (1960), Toshiba International Corporation (1970's) Toshiba Electrical Equipment (1974), Toshiba Chemical (1974), Toshiba Lighting and Technology (1989), Toshiba America Information Systems (1989) and Toshiba Carrier Corporation (1999). Toshiba is responsible for a number of Japanese firsts, including radar (1942), the TAC digital computer (1954), transistor television and microwave oven (1959), colour video phone (1971), Japanese word processor (1978), MRI system (1982), laptop personal computer (1986), NAND EEPROM (1991), DVD (1995), the Libretto sub–notebook personal computer (1996) and HD DVD (2005).

TOSHIBA		
Mother company name	*since*	*Till*
Toshiba Corporation	1984	2003

3.7.13. Intel Corporation

Intel is the world's largest semiconductor chip maker, based on revenue. The company is the inventor of the x86 series of microprocessors, the processors found in most personal computers. Intel was founded on July 18, 1968, as Integrated Electronics Corporation and based in Santa Clara, California, USA. Intel also makes motherboard chipsets, network cards and ICs, flash memory, graphic chips, embedded processors and other devices related to communications and computing. Founded by semiconductor pioneers Robert Noyce and Gordon Moore and widely associated with the executive leadership and vision of Andrew Grove, Intel combines advanced chip design capability with a leading–edge manufacturing capability. Originally known primarily to engineers and technologists, Intel's successful "Intel Inside" advertising campaign of the 1990s made it and its Pentium processor household names.

Intel was an early developer of SRAM and DRAM memory chips and this represented the majority of its business until the early 1980s. While Intel created the first commercial microprocessor chip in 1971, it was not until the success of the personal computer (PC) that this became their primary business. During the 1990s, Intel invested heavily in new microprocessor designs fostering the rapid growth of the PC industry. During this period Intel became the dominant supplier of microprocessors for PCs and was known for aggressive and sometimes controversial tactics in defence of its market position, particularly against AMD, as well as a struggle with Microsoft for control over the direction of the PC industry.

History and timeline

Intel was founded in 1968 by Gordon E. Moore (a chemist and physicist) and Robert Noyce (a physicist and co–inventor of the integrated circuit) when they left Fairchild Semiconductor. A number of other Fairchild employees also went on to participate in other Silicon Valley companies. Intel's third employee was Andy Grove, a chemical engineer, who ran the company through much of the 1980s and the high–growth 1990s. Grove is now remembered as the company's key business and strategic leader.

Mother company name	*since*	*Till*
Intel Corporation	1984	2003

3.7.14. STMicroelectronics NV

STMicroelectronics is an Italian–French electronics and semiconductor manufacturer headquartered in Geneva, Switzerland.

While STMicroelectronics corporate headquarters and the headquarters for Europe and emerging markets, are based in Geneva, the holding company, STMicroelectronics N.V. is registered in Amsterdam, Netherlands.

The company's US headquarters are in Carrollton, Texas. Headquarters for the Asia–Pacific region are based in Singapore and Japanese operations are headquartered in Tokyo. The company headquarters for the Greater China region are in Shanghai.

History and timeline

STMicroelectronics was formed in June 1987 by the merger of semiconductor companies SGS Microelettronica of Italy and Thomson Semiconducteurs, the semiconductor arm of France's Thomson. At the time of the merger the company was known as SGS–THOMSON but took its current name in May 1998 following the withdrawal of Thomson SA as an owner.

SGS Microelettronica and Thomson Semiconducteurs were both long–established semiconductor companies. SGS Microelettronica originated in 1972 from a previous merger of two companies:

- ATES (Aquila Tubi e Semiconduttori), a vacuum tube and semiconductor maker headquartered in the Abruzzese city of l'Aquila, who in 1961 changed its name into Azienda Tecnica ed Elettronica del Sud and relocated its manufacturing plant in the outskirts of the Sicilian city of Catania;
- Società Generale Semiconduttori (founded in 1957 by Adriano Olivetti).

Thomson Semiconducteurs was created in 1982 by the French government's widespread nationalisation of industries. It included:

- the semiconductor activities of the French electronics company Thomson;

- Mostek, a US company founded in 1969 by some ex–employees of Texas Instruments;
- Silec, founded in 1977;
- Eurotechnique founded in 1979 in Rousset, Bouches–du–Rhône as a joint–venture between Saint–Gobain of France and US–based National Semiconductor.
- EFCIS, founded in 1977;
- SESCOSEM, founded in 1969.

After its creation by merger in 1987, SGS–Thomson was ranked 14th among the top 20 semiconductor suppliers with sales of around US$850 million. The company has participated in the consolidation of the semiconductor industry since its formation, with acquisitions including:

- in 1989, British company Inmos known for its transputer microprocessors from parent Thorn EMI;
- in 1994, Canada–based Nortel's semiconductor activities;
- in 2002, Alcatel's Microelectronics division, which along with the incorporation of smaller ventures such as UK company, Synad Ltd, helped the company expand into the Wireless–LAN market.

On 8 December 1994, the company completed its initial public offering on the Paris and New York stock exchanges. Owner Thomson SA sold its stake in the company in 1998 when the company also listed on the Borsa Italiana in Milan.

Mother company name	*since*	*Till*
SGS Microelettronica	1984	1987
Thomson Semiconducteurs	1984	1987
SGS–THOMSON	1987	1998
STMicroelectronics NV	1998	2003

3.7.15. Infineon Technologies AG

Infineon Technologies AG was founded in 1999. As of September 30, 2007 Infineon has about 43,000 employees worldwide, 6000 of them involved in research and development. In the 2007 financial year, the company achieved sales of US$11.66

billion. In 2007 a 14.6% rise in projected calendar year revenues saw Infineon taking 10th place in iSuppli's global semiconductor sales ranking, thus gaining five places from 2006.

On May 1, 2006, Infineon's Memory Products division was carved out as a distinct company called Qimonda AG. It employs about 13,500 people worldwide.

History and timeline

Infineon Technologies AG, the former Siemens Semiconductor division, was founded in 1999 as a wholly owned spinoff of Siemens AG. In line with the structural changes affecting the electronics industry, the split was mainly caused by the price erosion in DRAMs in 1998. Anyway, it was a successful strategy: during the first year as a public company, Infineon led the market in producing chips for chips card. After the collapse of the industry in 2001, the company focused the development of its technologies (radio–frequency, mixed–signal, embedded control and DRAM) on some strategic applications in communications systems, automotive and industrial electronic systems.

Mother company name	*since*	*Till*
Infineon Technologies AG	1999	2003

3.7.16. Nippon Telegraph and Telephone Corporation

Nippon Telegraph and Telephone Corporation, commonly known as NTT, is a telephone company that dominates the telecommunications market in Japan. Ranked the 54th in Fortune Global 500, NTT is the largest telecommunications company in Asia and the third–largest in the world in terms of revenue.

History and timeline

Once established as a monopoly government–owned corporation in 1953, Nippon Telegraph and Telephone Public Corporation, the company was privatized in 1985 to encourage competition in the telecommunications market.

Because NTT owns most of the last mile, it enjoys oligopolistic control over land lines in Japan. In order to weaken NTT, the company was divided into a holding company (NTT) and three telecommunications companies (NTT East, NTT West and NTT Communications) in 1999.

The NTT Law regulating NTT East and West requires them to serve only short distance communications and obligates them to maintain telephone service all over the country. They are also obligated to lease their unused optical fibre (dark fibre) to other carriers at regulated rates.

NTT Communications is not regulated by the NTT Law.

NTT		
Mother company name	*since*	*Till*
Nippon Telegraph and Telephone Corporation	1984	2003

3.7.17. Verizon Communications Inc.

Verizon Communications Inc. is an American broadband and telecommunications company and a component of the Dow Jones Industrial Average. It was formed in 2000 when Bell Atlantic, one of the Regional Bell Operating Companies, merged with GTE. Prior to its transformation into Verizon, Bell Atlantic had merged with another Regional Bell Operating Company, NYNEX, in 1997.

History and timeline

Verizon was founded as Bell Atlantic Corporation by AT&T Corporation as one of seven Baby Bells that were formed due to an anti–trust judgement against them. It then inherited one of the seven Bell Operating Companies from American Telephone & Telegraph Company (later known as AT&T Corp.) following its breakup. Bell Atlantic's original roster of operating companies included:

- The Bell Telephone Company of Pennsylvania;
- New Jersey Bell Telephone Company;
- The Diamond State Telephone Company;
- The Chesapeake and Potomac Telephone Company;
- The Chesapeake and Potomac Telephone Company of Maryland;
- The Chesapeake and Potomac Telephone Company of Virginia;
- The Chesapeake and Potomac Telephone Company of West Virginia;

- Bell Atlantic originally operated in the U.S. states of New Jersey, Pennsylvania, Delaware, Maryland, West Virginia and Virginia, as well as Washington, D.C.

In 1994, Bell Atlantic became the first Regional Bell Operating Company to entirely drop the original names of its original operating companies. Ameritech and NYNEX (and SBC Communications in 2002) simply added DBA names to its operating companies; U S West and BellSouth had merged their operating companies.

In 1996, CEO and Chairman Raymond W. Smith orchestrated Bell Atlantic's merger with NYNEX. When it merged, it moved its corporate headquarters from Philadelphia to New York City. NYNEX was consolidated into this name by 1997.

Mother company name	*since*	*Till*
NYNEX Corporation	1984	1997
Bell Atlantic	1984	2000
General Telephone & Electronics Corporation (GTE)	1984	2000
Verizon Communications Inc.	2000	2003

3.7.18. Deutsche Telekom AG

Deutsche Telekom AG is a telecommunications company headquartered in Bonn, Germany. It is the largest telecommunications company in Germany and in the European Union.

As of June 2008, the German government still holds a 15% stake in company stock directly and another 17% through the government bank KfW.

History and timeline

Deutsche Telekom was formed in 1996 as the former state–owned monopoly Deutsche Bundespost was privatized.

All subsidiaries of Deutsche Telekom have names starting with "T–":

- T–Home (formerly T–Com), a legacy telephone and fixed network carrier and IPTV operator;

- T–Online, an internet service provider (ISP);
- T–Mobile, a mobile phone provider;
- T–Systems, a business division focused on providing to large customers.

A new Group structure was introduced on January 1, 2005, Deutsche Telekom has merged the two organizational business units of T–Com and T–Online into the Broadband/Fixed Network (BBFN) strategic business area. With around 40 million narrowband lines, over 9 million broadband lines and 14 million registered Internet customers, the Broadband/Fixed Network business area is one of the largest providers in Europe. R&D is now driven by Deutsche Telekom Laboratories (T–Labs).

Deutsche Telekom also holds substantial shares in other telecommunications companies, including Central European subsidiaries T–Slovak Telekom (Slovakia), Magyar Telekom (Hungary) and T–Hrvatski Telekom (Croatia), which are now fully consolidated into T–Com/T–Home. Furthermore, Magyar Telekom holds majority shares in Orbitel (Bulgaria), Combridge (Romania), Makedonski Telekom (Macedonia) and T–Crnogorski Telekom (Montenegro) all of which have also been rebranded and included under the T–Com/T–Home umbrella.

Mother company name	*since*	*Till*
Deutsche Bundespost	1984	1996
Deutsche Telekom AG	1996	2003

3.7.19. Vodafone Group plc

Vodafone is a British mobile network operator with its headquarters in Newbury, Berkshire, England, UK. It is the largest mobile telecommunications network company in the world by turnover and has a market value of about £75 billion (August 2008). Vodafone currently has operations in 25 countries and partner networks in a further 42 countries.

History and timeline

In 1982 Racal Electronics plc's subsidiary Racal Strategic Radio Ltd. won one of two UK cellular telephone network licences. The network, known as Racal Vodafone was 80% owned by Racal, with Millicom and the Hambros Technology

Trust owning 15% and 5% respectively. Vodafone was launched on 1 January 1985. Racal Strategic Radio was renamed Racal Telecommunications Group Limited in 1985. On 29 December 1986 Racal Electronics bought out the minority shareholders of Vodafone for £110 million.

In September 1988 the company was again renamed Racal Telecom and on 26 October 1988 Racal Electronics floated 20% of the company. The flotation valued Racal Telecom at GB£1.7 billion.[8] On 16 September 1991 Racal Telecom was demerged from Racal Electronics as Vodafone Group.

In July 1996 Vodafone acquired the two thirds of Talkland it did not already own for £30.6 million.

On 19 November 1996, in a defensive move, Vodafone purchased Peoples Phone for £77 million, a 181 store chain whose customers were overwhelmingly using Vodafone's network.

In a similar move the company acquired the 80% of Astec Communications that it did not own, a service provider with 21 stores.

On 29 June 1999 Vodafone completed its purchase of AirTouch Communications, Inc. and changed its name to Vodafone Airtouch plc. Trading of the new company commenced on 30 June 1999.[13] To approve the merger, Vodafone sold its 17.2% stake in E–Plus Mobilfunk. The acquisition gave Vodafone a 35% share of Mannesmann, owner of the largest German mobile network.

On 21 September 1999 Vodafone agreed to merge its U.S. wireless assets with those of Bell Atlantic Corp to form Verizon Wireless. The merger was completed on 4 April 2000.

In November 1999 Vodafone made an unsolicited bid for Mannesmann, which was rejected. Vodafone's interest in Mannesmann had been increased by the latter's purchase of Orange, the UK mobile operator.

However, on 3 February 2000 the Mannesmann board agreed to an increased offer of £112bn, then the largest corporate merger ever.

The EU approved the merger in April 2000. The conglomerate was subsequently broken up and all manufacturing related operations sold off.

On 28 July 2000 the Company reverted to its former name, Vodafone Group Plc.

vodafone		
Mother company name	*since*	*Till*
Racal Electronics plc	1984	1985
Racal Telecommunications Group Limited	1985	1988
Racal Telecom	1988	1991
Vodafone Group plc	1991	1999
Vodafone Airtouch plc	1999	2000
Vodafone Group plc	2000	2003

3.7.20. France Télécom

France Télécom is the main French telecommunications company, it is the third–largest in Europe and one of the largest in the world. It currently employs about 191,000 people (half outside of France) and has nearly 159 million customers worldwide (2007). In 2008 the group had revenue of €53.5 billion.

History and timeline

Up to 1988, France Télécom was known as the Direction Générale des Télécommunications, a division of the Ministry of Posts and Telecommunications. It became autonomous in 1990. It was privatized by Lionel Jospin's Plural Left government starting in January 1, 1998. The French government, both directly and through its holding company ERAP, continues to hold a stake of almost 27% in the firm.

In Summer 2003 France Télécom sold a 48% shareholding in Telecom Argentina, which it had jointly run with Telecom Italia, to the Argentinian Werthein family. FT now holds only 2% of the firm. In 2003 FT sold CTE El Salvador.

france telecom		
Mother company name	*since*	*Till*
Direction Générale des Télécommunications	1984	1988
France Télécom	1988	2003

Extended Summary

4.1. Introduction

One of the most important elements affecting innovation performance are people who generate ideas, discover technological opportunities, solve technical problems and develop manufacturing processes and prototypes. Ever since the corporate research and development (R&D) became an important strategic arm of private firms, inventive processes became more collective than individual.

The formation of R&D teams can be traced back to heterogeneity in terms of geography, sector, ethnicity and culture, to mention a few. This heterogeneity of the team is one of the key drivers of innovation. However, it may also have its drawbacks.

4.2. Objectives and research questions

The current research work aims to understand how the degree of the intensity of international collaboration in inventive activities has varied over the years.

Specifically, it addresses the following research questions concerned with the differences across sectors and countries:

1. What was the path of internationalization of groups of inventors in the last thirty years?
2. Does the speed of internationalization, measured as geographical concentration of the group of inventors, differs across sectors?
3. Does the behavior of multinational enterprises (MNEs) in internationalizing their inventive activities differ from that of the whole sectors?
4. How different is the behavior of MNEs, in their own sector, with respect to their technological specialization of inventive activity?
5. How different is the behavior of MNEs, in their own sector, with respect to their technological complexity of inventive activity?

The first part of the research work (Chapter 1) describes the most important contributions in the direction of having a comprehensive picture of the organization of knowledge intensive activities in the global landscape. In order to understand knowledge intensive activities, the focus is on MNEs, the most important unit of analysis for technological transfer in the global environment.

The second part (Chapter 2) analyses the trend of internationalization of inventive activity over a certain fixed time period, highlighting the differences between advanced countries and the developing ones.

In the final section (Chapter 3) we adopt an approach of estimating the degree of internationalization within countries, within sectors and within 20 MNEs identified as the top five in four important sectors: automotive, pharmaceuticals, telecommunications and semiconductors.

4.3. Limitations of existing literature

While academic researchers gave attention to systemic and aggregate aspects of the inventive activity, they only took a scant look at the actors involved in the process – inventors.

The scarcity of the literature on this topic is noticeable when compared to the huge volume of literature about the performance of scientific researchers.

Several researchers have exploited in various ways the information contained in patent data (see, among others, Patel and Pavitt, 1991; Patel and Vega, 1991, and Le Bas and Serra, 2002). Our research work also uses patents data. While most previous studies have considered the patent portfolios of (multinational) firms, in this study we attribute patents to nations, by exploiting the fact that patents data provide separate information on the residence of the inventors and of the applicant countries.

Prior research on MNEs using patent data has generally taken the ownership and affiliate structure of a firm as constituted in a single year and simply assigned patents to parent companies assuming no changes in this structure over time (Cantwell 1995, Patel and Pavitt 1991). Such an approach ignores factors related or arising from mergers and acquisitions. This is likely to lead to serious problems in the assignment of patents to parent companies, especially in the late 1980s when many large cross-border acquisitions took place. To ensure that affiliate patents were allocated properly to the parent company, we traced the timing of mergers, acquisitions, and dispositions from 1984 to 2004.

4.4. Methododolgy

The empirical part of this study builds upon a subset of a larger dataset constructed and maintained by CRIOS at Bocconi University (Milan, Italy). We take advantage of a unique source of firm-level innovation data derived from European patent records. Data processing consisted mainly in a thorough work of cleaning and standardization of rough information provided by the EPO.

Patent data, as a measure of inventive output, have both positive outcomes and shortcomings (Smith, 2005, and Griliches, 1990). Many innovations, particularly of production processes, do not result in any patent applications, and firms often prefer to protect their inventions by keeping them secret, rather than by asking for the protection afforded by patents. However, this limitation of patent statistics is less important when the focus is on international innovation, because in that case the propensity to patent is bound to be higher, given that trade secrets are more difficult to keep in situations where the innovators reside in several countries and may belong to distinct organizations.

While not all innovations are patented, the opposite is also true – that is, not all patented inventions produce innovations. Patents may have very different values, and for each superstar patent, which introduces a very relevant and successful product or process, there are countless others with limited or no use. If a given patent involves only people and organizations residing in the same country, we define the patent as "national". If, on the other hand, at least one inventor or one applicant resides in a country different from that of the others, then we call the patent "international".

In order to fulfill the objective of understanding the extent of internationalization present in the inventive activities, especially the ones of MNEs, our research work makes a fruitful attempt at calculating internationalization indexes.

To begin with, the role of MNEs in the process of technology transfer is explained. In order to gain a deeper understanding of the whole process four important sectors are discussed. The focus is on automotive, pharmaceutical, telecommunications and the semiconductor sectors.

Following the description, chapters 2 and 3 proposes indexes to answer the research questions indicated in section 2. This indexes analyze some information contained in EPO patents, in particular the residence of the inventors, the technological class (with two levels of aggregation: OST30 and IPC 4-digit) and the technological specialization of the cited patents.

The purpose of these indexes is to make us understand:

- The degree of geographical diversity (internationalization) of the research groups;
- The extent to which a single multinational company technologically specialized its inventive activities;
- If the reference technology on which an invention is based is technologically specialized or it is based on different technologies.

Here is the detail of the four indices used:

1. Index of Inventors' Group Internationalization (IGI): This index measures the internationalization of a research group on a range going from 0 to 1, being 0 in the case all inventors reside in the same country and 1 if each of them resides in a different one. To capture the underlying heterogeneity the Herfindahl-Hirshman index (HHI) is used and the IGI is defined as its complement to one.

   Contrarily to all previous indexes based on cross-country patents, the IGI provides a measure of internationalization of the research group itself, adding a dimension to the set of variables describing a patent. Moreover, being a normalized measure, it allows for the comparison of groups (and therefore of patents) with a different number of inventors and countries of residence.
2. Index of Technological Specialization for MNEs (ISTEM): this is an index of concentration of the patents granted to a multinational company in a given year in terms of OST 30 technological class. Its purpose is to provide, for every year of observation, an approximation of the extent to which a single multinational company technologically specializes its inventive activities. A high level of

concentration of the technological classes in which the firm patented would entail that such firm specialized its R&D activities in a narrow technological field. In order to measure the technological specialization extent, differently from all the other indicators presented in this paper, the ISTEM is calculated at firm level and not at patent level. From a methodological point of view also this index is computed as a revised version of the HHI.

3. Index of Utilization Specificity of Patents (ISUB): this index can be seen as an inverse index of the general purpose degree of a technology. It measures the concentration of four-digit IPC macro-classes of every patent. A high ISUB will be attributed to an invention which finds most of its use in a small part of the technological classes to which it is assigned, or – in the extreme case – which belongs only to one class. On the other hand, a low value of this index will be scored by patents with general purpose, i.e. which are equally belonging to different technological classes. An annual average ISUB can be calculated for companies as well by aggregating patents at the company level. The resulting index will approximate ISTEM indicator of observed firms.
4. Index of Technological Complexity of Patents (ICTEB): this index is also based on an HHI-based index of concentration. Every patent cites other patents upon which its technology relies on. Each one of these patents is assigned to more OST30 classes, which indicates its membership to a number of determined technological families. The ICTEB of a patent is an index of diversity of the patents it cited in terms of OST30 classes. The degree of diversity in the technological classes of patents cited by one patent can be used as a proxy for its complexity. By complexity, we mean the need to resort to the knowledge embodied in more technological classes in order to generate the concerned patented invention. A patent with ICTEB=0 will have a low complexity in the sense that its own achievement will require the knowledge embedded in only one technological class.

All these indexes are applied to the EPO PATSTAT database; with these indexes an empirical analysis is conducted. The analysis helps in exploring the main trends in the internationalization from patent applications data from 1979 to 2008.

These indexes are deployed to explore four key sectors: Telecommunications, Semiconductors, Pharmaceuticals, Automotive.

A crucial point of departure is the keen attention paid towards structural changes experienced by the MNEs. These structural changes are incorporated while calculating the indexes. As a result, the final analysis takes into account the role played by structural changes while explaining the final results. Structural changes include details of mergers and acquisitions.

4.5. Results

The results are derived from the empirically analysis conducted on different sectors with the help of patent data statistics.

A comprehensive explanation of both the phenomena of R&D globalization and internationalization within MNEs is provided. The detailed explanation of prior scholarly work helps conclude that, despite geographical and cultural distances, a team which constitutes of researchers with diverse background may generate highly innovative outcomes.

Here it follows a brief description of each index behavior along in the observed sample. Along with the index behavior a sketch of the underlying analysis is added.

The degree of internationalization, assessed on the basis of teams of researchers with heterogeneous geographical origins, exhibits an almost exponential increase over the whole observed period.

This may lead one to conclude that an overall trend towards geographical heterogeneity of inventors in such groups has taken place. However, despite the sharp increase over time, the average level of heterogeneity was always quite low.

In chapter 2, a similar result is shown by OECD research groups. However it is interesting to notice that, contrary to general evidence, in those cases where at least one inventor comes from BRICS or the Asian Tigers, the internationalization index shows a decreasing path.

After having provided large evidence of such phenomenon, variations in intensity of internationalization (and its very presence) across technological sectors were computed. From a sectorial perspective, evidence shows, on one hand, that Chemical and Pharmaceutical technologies are more likely to be generated by more heterogeneous research groups, as it appears that there are more knowledge exchange and sharing connection among these sectors globally; on the other hand, Electronic Engineering, Instruments and Mechanical Engineering patents show, on average, more geographical homogeneity in groups of inventors.

Similar results are observed when analyzing internationalization in terms of the two macro-areas: the BRICS and the OECD countries. At this level of analysis it is worth noticing the exception of telecommunication technologies, where inventive co-operation among macro-areas appeared to be a major driver of internationalization in the last decade.

The ISTEM showed whether a high level of specialization is observed across all sectors or it is a specific feature of few of them. The five years index suggested that semiconductor and telecommunication are the most specialized sectors. On the contrary, Automotive and Pharmaceuticals present a low specialization level, suggesting either that patents belonging to a specific sector could be assigned to many different classes or that there are no prevalent classes assigned to their patents.

The ISUB gave very clear and comprehensive idea of the last five years trend. Over the chosen time span it is possible to observe different kinds of behavior. For example Automotive, Semiconductors and Telecommunications display similar stationary behaviors with values around 0.7/0.8 and never exiting the [0.65; 0.8] band; to the contrary pharmaceutical sector exhibits both a downward and upward trend which generates a “throat” during the 1994-1998 period.

The last index, the ICTEB – capturing technological complexity of patents, showed a general decreasing trend in each of the analyzed sectors.

Two interpretations could be drawn from this decreasing pattern:

- An increase in the asymmetry between classes cited by patents, meaning that, independently of sector specificities classes seem to form over time specific groups characterized by high with-in citations (citations between classes of the same group) and low between citations (citations between classes of different groups).

- A decrease in the number of cited classes. Here a twofold explanation is possible. On one side it means there exists a decline in the overall number of technological classes being patent-oriented; under this kind of hypothesis; on the other side specialization occurs in such a way that complementarities among different classes diminish over time, pushing toward a decrease in the number of classes cited, on average, by a patent.

The most important thing to notice here is that apart from semiconductor sector, which is the one that presents the lowest value of the index in all but one period, the other sectors start at almost the same level (around 0.5) in the first period and then evolve differently. Telecommunications experiences the sharpest decline and its value of the ICTEB index always lies below the others (excluding Semiconductors). Automotive and Pharmaceuticals exhibit a smoother behavior with the latter never breaking the 0.4 lower bound. An additional interesting feature consists in the analysis of most recent trends of technological complexity if we compare them with respect to the ones found in remaining of the sample. In the first decades of the sample the vast majority of sectors clearly shows a decreasing trend in the technological complexity of the patents; in addition, this behavior is evident also at firm level and not only when we aggregate MNEs performances to obtain sectorial ones. To the contrary, the situation changes when we focus in the last 10 years: behavior of the ICTEB along sectors in much more heterogeneous. In particular, it is possible to observe that the number of sectors displaying an increasing technological complexity in the inventions they patent (Pharmaceuticals and Telecommunications) is equal to number of sectors with decreasing ICTEB (Automotive and Semiconductor. Moreover, that the majority (12/20) of firms show an increasing ICTEB, with the sole firms in the automotive sector exhibiting a negative growth.

Up to now the analysis pays attention towards the behavior of proposed indexes at sector level, after integrating individual firm performances in the sector-level version of the index. This approach provides general evidences on the extent to which R&D activities differ across sectors in the output they produce and in the composition of research groups devoted to produce such an output. What emerges is that dissimilarities are much greater than affinities, with the exception of technological complexity of the patents, which is the sole dimension along which all the analyzed sectors exhibit the same (decreasing) pattern.

Another interesting dimension is given by a comparison of the variability around sector-trends between one sector and another. In such a way we do not only capture the performance of the sector taken as a whole, but we can also observe how MNEs from the respective sectors deviate from the aggregate trend.

Proceeding along this stream and keeping fixed the period of analysis we notice that, with respect to the IGI index, the Semiconductors is the sector with the highest degree of homogeneity, having all the relevant MNEs displaying very similar patterns, while in Automotive and Pharmaceuticals MNEs show very contrasting behaviors of the index, having both peaks and troughs.

Moving to the ISTEM the picture is reversed. MNEs with most similar behavior are those operating in the Pharmaceuticals while automotive and semiconductor firms show extremely heterogeneous trends. Focusing instead on the ISUB, the index measures the degree of utility specialization. It is analysis highlights the similar behavior amongst the while Semiconductors and Telecommunications show a very heterogeneous pattern, with always no more than 2 firms over 5 having an analogous trend.

With regard to the last indicators proposed in this research work, the ICTEB, Semiconductors and Telecommunications are again the two sectors presenting a higher degree of heterogeneity in the behavior of their relevant MNEs; while in the other two sectors each firm displays a pattern very similar to the other.

While concluding it is interesting to underline that apart from sectorial differences in the aggregate value of the four indexes proposed in this work, there exists an additional source of intra-sector heterogeneity. It is given by the variability of the behavior among MNEs within each sector. In general Telecommunications and, in particular, Semiconductors are the two sectors with a more pronounced variability, having firms performing in very different ways. The exception is constituted by the case of the more relevant of our indexes, the IGI, where MNEs working on semiconductors show a very homogeneous evolution of their attitude toward internationalization and globalization of research activities. This is an important result:

in the semiconductor industry R&D is structured in a way that MNEs recognize the need for more (or less) geographically heterogeneous research groups but, despite this similarity, the outcome of such a research is very different in terms of technological classes of the patent being analyzed and the respective patents cited by it.

Moreover, the same kind of analysis can be done for all the other sectors and additionally, it is possible to underline whether similarities of behavior amongst the four index. We would like to highlight that this is another strength of our effort.

4.6. Contributions to existing literature

Our approach appears to have very little partial antecedent (Guellec and van Pottelsberghe de la Potterie, 2001; Picci, 2010; Montobbio and Sterzi, 2013). However, apart from the fact that today almost a decade more of data is available for analysis; our research differs in many respects from the previous literature. An innovative dimension of this work lies in its treatment of patent information and in the use the patent information to build indicators.

We can claim the validity, supported by evidence (explained in chapter 2) of our new indicator based on cross-country patent data as an estimator of the extent of internationalization of inventive activity, i.e. of geographical heterogeneity among inventors in research groups. Unlike the large majority of previous studies providing cross-country patent indicators, we deliberately choose to disregard the topics of geographical difference in the location of R&D activities and applicant headquarters, as well as international R&D collaboration among firms in general, but to focus directly on the geographical composition of research groups. In such a way we capture the precise effect on internationalization of R&D activities produced by the extent researchers working in the same group but coming from different countries of origin, bringing different cultural backgrounds into play.

Although topics addressed in this work are highly interdependent and their joint study is likely to be necessary in the quest for a comprehensive theory over the globalization of R&D, our aim here is just to provide new methodological tool, composed by one general index, the IGI, and three specific indexes for MNEs: the ISTEM, the ISUB, the ICTEB.

The investigation of time-behavior of previous indexes is a fairly new approach with respect to the existing literature which may provide important information about the dynamics of internationalization and globalization of R&D by disclosing relevant trends captured at different level of aggregation.

We claim, also based on the evidence (explained in chapter 2), the validity of similar indexes based on patents' data to produce simple measures of specific dynamics that could be used as proxies for the analysis of inventive activities in MNEs and how these activities differ (or not) across sectors.

In addition, as introduced in the previous section, our analysis allows for the comparison amongst sectors of the variability with which inventive activities take place within an industry. This provides a more complex but even more informative analysis of sectorial differences in how MNEs conduct their R&D.

4.7. Conclusions

Firstly, we have explored and analyzed the main trends of internationalization of R&D team in the MNEs. The main contribution is the development of an index which helps in understanding the internationalization of knowledge production and diffusion.

Secondly, as the dataset used covers a period of nearly 29 years, the results help in having a long term analysis. While performing the analysis on the basis of geographical index we divide the patents according to the presence of inventors from BRICS and from the Asian Tigers, and further to their technological class.

Furthermore, the results are explored in four big sectors: Automotive, Pharmaceuticals, Semiconductors, and Telecommunications. In addition to considering four key sectors, the structural fluctuations owing to mergers and acquisitions experienced by every sector are also considered. This approach is able to deliver more reliable results compared with the previous ones which assigned patents to parent companies assuming no structural changes over time. The problems linked to the older approach are based on the intrinsic characteristics of patenting activity which is strategic and could be influenced by changes in the group structure. The approach adopted in this chapter rules out the emergence of such problems.

Finally, our approach provides an additional dimension of the analysis which constitutes in the comparison of the intra-sector heterogeneity in MNEs' behavior along the proposed dimensions. To best of our knowledge this kind of analysis is not encompassed by the existing literature.

4.8. Limitations and directions for future research

This research work opens new avenues like understanding internalization of R&D teams with the help of indexes using patent data statistics.

This approach could be further used to understand the antecedents of patenting activity and the resulting consequences. Along with this, it might be interesting to explore if features of the patenting activity change with the market conditions or the expenditure of the groups.

Here are some possible limitations and directions for future research:

- The use of European Patent Office may not take into account many of the applications belonging to applicants from developing countries that prefer the USPTO as their first patent office: future research may address this limitation by using USPTO patent data;
- The analysis done with the internationalization index for the inventors group could take in account the citizenship of the inventors, as this data is less sensitive to changes: future research may address this limitation by using the database on the mobility of the inventors (Miguelez and Fink, 2013);
- The analysis done with the internationalization index for the inventors group could take in account the ethnicity of the inventors: future research may address this limitation by using the database on ethnicity of the inventors through a name-surname analysis (Fiscella and Fremont, 2006) also relating with immigration policies of individual country;
- A weakness of this research work is the use of a single database: future research may address this limitation by connecting the patent databases with other sources at micro and macro level which would allow the analysis through econometric models;

- The analysis on 20 MNEs did not allow us to evaluate effectively the effects of corporations on sectors due to the inadequate number of patents granted: it would be appropriate to identify a mechanism (algorithm) for the semi-automatic detection of MNEs in the patent database as any manual mechanisms would take a lot of time for manual matching with other databases;
- The use of the classification OST30 does not allow us to do a proper comparative analysis with other data and information using the sectorial classification denominated ISIC (International Standard Industrial Classification of All Economic Activities): future research may address this limitation by creating a concordance table based on the probabilistic approach for joint analyses of patenting;
- Further research is needed to analyze and understand the reason for the decrease in the trend of internationalization of the inventive activities for patents involving BRICS countries and Asian Tigers since 1994;
- Further research is needed to analyze and understand the reason for the different speed in internationalization trends for some technology.

The aim of this extended summary was to abstract the research work done, that is extensively described in the previous three chapters and have been submitted in partial fulfillmen of the requirements for the degree of Doctor of Philosophy in Economics and Innovation Management, with European mention, at Universitdad Complutense de Madrid.

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Resumen Extendido

5.1 Introducción

Uno de los elementos más importantes que afecta al rendimiento de la innovación son los individuos que generan las ideas, descubren oportunidades tecnológicas, resuelven problemas técnicos y desarrollan procesos de fabricación y prototipos. Desde que las actividades de investigación y desarrollo (I+D) se convirtieron en un arma estratégica importante de empresas privadas, los procesos de invención se volvieron más colectivos que individuales.

La formación de equipos de I+D tiene un origen muy heterogéneo en términos de geografía, sector, grupo étnico y cultural, por mencionar algunos. Esta heterogeneidad del equipo de investigación es uno de los factores clave de la innovación. Sin embargo, esto también puede tener sus inconveniente.

5.2 Objetivos y preguntas de investigación

El objetivo de este trabajo de investigación es entender cómo el grado de intensidad en la colaboración internacional de las actividades inventivas ha variado a lo largo de los años.

Específicamente, este trabajo de investigación busca contestar a las siguientes preguntas de investigación relacionadas con la diferencia entre sectores y países:

1. ¿Cuál fue la tendencia de la internacionalización de los grupos de inventores en los últimos treinta años?
2. ¿La velocidad de la internacionalización, medida como la concentración geográfica del grupo de inventores, difiere entre sectores?
3. ¿El comportamiento de las empresas multinacionales (EMN) en la internacionalización de sus actividades inventivas difiere de la de los sectores enteros?
4. ¿Cómo se diferencia el comportamiento de las EMN, en su propio sector, en relación con su especialización tecnológica de la actividad inventiva?

5. ¿Cómo se diferencia el comportamiento de las EMN, en su propio sector, en función de su complejidad tecnológica de la actividad inventiva?

La primera parte del trabajo de investigación (Capítulo 1) describe las contribuciones más importantes a fin de tener una visión global de la organización de las actividades intensivas en conocimiento. Con el fin de entender las actividades intensivas en conocimiento, la nuestra atención se centra en las EMN, la unidad más importante de análisis para la transferencia tecnológica en el medio ambiente global.

La segunda parte (Capítulo 2) analiza la tendencia a la internacionalización de la actividad inventiva en un determinado período de tiempo, poniendo de relieve las diferencias entre los países avanzados (OECD) y de los países en desarrollo.

En la sección final (Capítulo 3) se adopta un enfoque para estimar el grado de internacionalización entre los países, entre los sectores y entre 20 empresas multinacionales identificadas entre las cinco primeras en cuatro importantes sectores: automotriz, farmacéutico, telecomunicaciones y semiconductores.

5.3 Limitaciones de la literatura existente

Mientras que los investigadores dieron atención a los aspectos sistémicos y el agregado de la actividad inventiva, ellos sólo dieron poca importancia a los actores involucrados en el proceso – los inventores.

La escasez de la literatura sobre este tema es notable en comparación con el enorme volumen de literatura sobre el desempeño de los investigadores científicos.

Varios investigadores han aprovechado de diversas formas la información contenida en los datos de patentes (véase, entre otros, Patel y Pavitt, 1991; Patel y Vega, 1991, y Le Bas y Serra, 2002). Nuestro trabajo de investigación también utiliza datos de patentes. Aunque la mayoría de los estudios anteriores han examinado las carteras de patentes de EMN, en este trabajo atribuimos patentes a los países, aprovechando el hecho de que los datos de patentes proporcionan información independiente sobre la nacionalidad de los inventores y de los países de las empresas candidatas.

Las investigaciones anteriores sobre las EMN a partir de datos de patentes ha tomado generalmente la estructura de propiedad y filial de una empresa en su composición de un sólo año y simplemente asignaron patentes a las empresas matrices suponiendo que no hay cambios en esta estructura en el tiempo (Cantwell 1995, Patel y Pavitt, 1991). Este enfoque hace caso omiso de los factores relacionados o derivados de las fusiones, adquisiciones y enajenaciones. Esto es probable que conduzca a graves problemas en la asignación de patentes a las empresas matrices, especialmente a finales de la década de 1980 cuando tuvieron lugar muchas de las grandes adquisiciones transfronterizas. Para asegurarse de que las patentes de afiliados fueron asignados correctamente a la sociedad dominante, hemos seguido el calendario de las fusiones, adquisiciones y enajenaciones 1984–2004.

5.4 Métodos

La parte empírica de este estudio se basa en un subconjunto de datos de una gran base de datos construida y mantenida por el Centro CRIOS de la Universidad Bocconi de Milán (Italia). Nos aprovechamos de una fuente única de datos sobre innovación a nivel de empresas derivadas de registros de patentes europeas. El tratamiento de la información consistió principalmente en un trabajo exhaustivo de limpieza y normalización de la información proporcionada por la Oficina Europea de Patentes (OEP).

Los datos de patentes, como una medida de la producción inventiva, deberían tener tanto los resultados positivos como las deficiencias (Smith, 2005, y Griliches, 1990). Muchas innovaciones, sobre todo de los procesos productivos, no dan lugar a solicitudes de patentes y las empresas a menudo prefieren proteger sus invenciones manteniéndolas en secreto, en lugar de pedir la protección por patentes. Sin embargo, las limitaciones de las estadísticas de patentes es menos importante cuando la atención se centra en la innovación internacional, ya que en ese caso, la propensión a la patente está obligado a ser mayor, dado que los secretos comerciales son más difíciles de mantener en situaciones en las que los innovadores residen en varios países y puede pertenecer a distintas organizaciones.

No todas las innovaciones están patentadas ni todos los inventos patentados producen innovaciones. Las patentes pueden tener valores muy diferentes, y por cada patente superestrella, que introduce un producto o un proceso muy importante y exitoso, hay muchos otros con un uso limitado o nulo. Si una determinada patente involucra sólo a las personas y a las organizaciones que residen en el mismo país, la definimos como "nacional". Si, por otro lado, al menos un inventor o un solicitante reside en un país diferente al de los demás, la llamaremos patente "internacional".

Para cumplir con el objetivo de comprender el alcance de la internacionalización presente en las actividades inventivas, especialmente los de las EMN, nuestro trabajo de investigación hace un intento fructífero en el cálculo de los índices de internacionalización.

Para empezar, se explica el papel de las EMN en el proceso de transferencia de tecnología. Con el fin de obtener una comprensión más profunda de todo el proceso es que se discuten cuatro sectores importantes. La atención se centra en los sectores de automotriz, productos farmacéuticos, telecomunicaciones y semiconductores.

Después de la descripción, en el capítulo 2 y 3 se propone el diseño de índices para medir la internacionalización indica en el apartado 2. En estos índices se analiza alguna información contenida en las patentes EPO, en particular, la residencia de los inventores, la clase tecnológica (con dos niveles de agregación: OST30 e IPC–4 dígitos) y la especialización tecnológica de las patentes citadas.

El objetivo de estos índices es hacernos entender:

- El grado de diversidad geográfica (internacionalización) de los grupos de investigación;
- El grado de especialización tecnológica de las actividades inventivas de cada empresa multinacional;
- Si la tecnología de referencia en el que se basa la invención es tecnológicamente especializada o se basa en diferentes tecnologías.

Aquí está el detalle de los cuatro índices utilizados:

1. Índice del Grupo de Internacionalización de Inventores (IGI): este índice mide la internacionalización de un grupo de investigación en un rango que va de 0 a

1, siendo 0 en el caso de todos los inventores residen en el mismo país y 1 si cada uno de ellos reside en uno diferente. Para capturar la heterogeneidad subyacente se utiliza el índice de Herfindahl-Hirschman (HHI) y se define el índice como su complemento a uno.

Contrariamente a todos los índices previos basados en patentes internacionales, el IGI proporciona una medida de la internacionalización del propio grupo de investigación, añadiendo una dimensión al conjunto de variables que describen una patente. Además, al ser una medida normalizada, nos permite la comparación de los grupos (y por lo tanto de patentes) con un número diferente de inventores y de países de residencia.

2. Índice de Especialización Tecnológica de las EMN (ISTEM): es un índice de concentración de las patentes concedidas a una EMN en un año dado, en términos de OST 30 clase tecnológica. Su objetivo es proporcionar, por cada año de observación, una aproximación de la medida en la que una EMN es especializada tecnológicamente en sus actividades inventivas. Un alto nivel de concentración de las clases tecnológicas en las que la EMN es patentado implicaría que las actividades de I+D en la EMN es especializada refieran a un estrecho campo tecnológico. Con el fin de medir el grado de especialización tecnológica, a diferencia de todos los demás indicadores que se presentan en este trabajo, el ISTEM se calcula a nivel de empresa y no a nivel de patentes. Desde un punto de vista metodológico también este índice se calcula como una versión revisada del HHI.
3. Índice de Utilización Especificidad de Patentes (ISUB): este índice puede ser visto como un índice inverso del grado de propósito general de una tecnología. Se mide la concentración de cuatro dígitos IPC macro-clases de todas las patentes. Un alto ISUB se puede atribuir a una invención que encuentra la mayor parte de su uso en una pequeña parte de las clases tecnológicas a las que se ha asignado, o – en el caso extremo – que sólo pertenece a una clase. Por otro lado, un valor bajo de este índice se marcará por las patentes con propósito general, es decir, que son igualmente pertenecientes a diferentes clases tecnológicas. Un ISUB promedio anual puede calcularse para las empresas, así

agregando patentes a nivel de empresa. El índice resultante se ISTEM indicador aproximado de las empresas observadas.

4. Índice de Complejidad Tecnológica de Patentes (ICTEB): este índice se basa en un índice de concentración HHI-based. Cada patente menciona otras patentes sobre la cual se basa en su tecnología. Cada una de estas patentes se asigna a las clases más OST30, lo que indica su pertenencia a un número de familias tecnológicas determinada. El ICTEB de la patente es un índice de diversidad de las patentes que citó en términos de OST30 clases. El grado de diversidad en las clases tecnológicas de patentes citadas por una patente puede ser utilizado como una medida de su complejidad. Por la complejidad, nos referimos a la necesidad de recurrir al conocimiento incorporado en las clases más tecnológicas con el fin de generar la invención patentada en cuestión. Una patente con ICTEB=0 tendrá una baja complejidad en el sentido de que su propia realización requerirá el conocimiento incorporado en una sola clase tecnológica.

Estos índices se aplican a la base de datos EPO PATSTAT. Con la ayuda de estos índices se llevó a cabo un análisis empírico. El análisis ayuda a explorar las principales tendencias en la internacionalización de los datos de las solicitudes de patentes que van desde 1979 hasta 2008. Estos índices se han desplegado para explorar los cuatro sectores claves identificados en el párrafo anterior.

Un punto fundamental de partida es la aguda atención a los cambios estructurales experimentados por las EMN. Estos cambios estructurales se incorporan al calcular los índices. Como resultado, el análisis final toma en cuenta el papel desempeñado por los cambios estructurales mientras que explica los resultados finales. Los cambios estructurales incluyen detalles de las fusiones y adquisiciones.

5.5 Resultados

Los resultados se derivan del análisis empíricamente llevado a cabo en los diferentes sectores con la ayuda de las estadísticas de datos de patentes.

Se proporciona una explicación completa del fenómeno de la globalización de I+D dentro de las EMN o de I+D de internacionalización dentro de las EMN. Una justificación detallada del trabajo académico en esta área permite concluir que, a pesar de la distancia geográfica y cultural, la constitución de un equipo de investigadores con diferentes habilidades y diversos conocimientos puede generar resultados muy innovadores.

Aquí sigue una breve descripción de cada comportamiento índice a lo largo de la muestra observada. Junto con el comportamiento índice se agrega un boceto del análisis subyacente.

El cálculo de la internacionalización sobre la base de los equipos que tienen miembros con diferentes orígenes geográficos muestra un aumento casi exponencial de la internacionalización de los grupos de inventores durante todo el período observado.

Esto puede llevar a la conclusión de que una tendencia global hacia la heterogeneidad geográfica de los inventores de estos grupos ha tenido lugar. Sin embargo, el nivel medio de esta heterogeneidad fue siempre bastante baja.

En el capítulo 2, un resultado similar se muestra por grupos de investigación de la OCDE. Sin embargo, es interesante notar que, contrariamente a la evidencia en general, en aquellos casos en los que al menos un inventor proviene de BRICS o los tigres asiáticos, el índice de internacionalización muestra una tendencia decreciente.

Después de haber presentado la gran evidencia de este fenómeno, se calcularon las variaciones en la intensidad de la internacionalización (y su sola presencia) en todos los sectores tecnológicos. Desde una perspectiva sectorial, la evidencia muestra, por un lado, que las tecnologías para productos químicos y farmacéuticos son más propensos a ser generados por los grupos de investigación más heterogéneos, ya que parece que hay más intercambio de conocimiento y compartir la conexión entre estos sectores a nivel mundial, y por otro lado, Ingeniería Electrónica, Instrumentos y patentes de Ingeniería Mecánica muestran, en promedio, la homogeneidad, más geográfica en grupos de inventores.

Resultados similares se observaron en el análisis de la internacionalización en términos de los dos macro-áreas: los BRICS y los países de la OCDE. En este nivel de análisis, vale la pena notar la excepción de las tecnologías de las telecomunicaciones, donde apareció inventiva cooperación entre las macro -áreas a ser un importante motor de la internacionalización en la última década.

El ISTEM mostró si un alto nivel de especialización se observa en todos los sectores o es una característica específica de algunos de ellos. El índice de cinco años sugiere que los semiconductores y telecomunicaciones son los sectores más especializados. Por el contrario, automóviles y productos farmacéuticos presentan un bajo nivel de especialización, lo que sugiere o bien que las patentes que pertenecen a un sector específico podrían ser asignados a diferentes clases o que no existen las clases dominantes asignados a sus patentes.

El ISUB dio una idea muy clara y completa de la tendencia de los últimos cinco años. Durante el período de tiempo elegido es posible observar diferentes tipos de comportamiento. Por ejemplo, Automóviles, Semiconductores y Telecomunicaciones mostraron comportamientos estacionarios similares con valores alrededor de 0,7 / 0,8 y nunca salieron de la banda de [0,65; 0,8]; por el contrario el sector de productos farmacéuticos, exhibió una tendencia descendente y ascendente que genera una "garganta" en el período 1994-1998.

El último índice, el ICTEB – captando la complejidad tecnológica de patentes – mostró una tendencia a la disminución general de cada uno de los sectores analizados.

Dos interpretaciones se pueden extraer de este patrón decreciente:

- Un aumento de la asimetría entre las clases citadas por las patentes, lo que significa que, independientemente de las clases de especificidades sectoriales parecen formar por los grupos de tiempo específicos caracterizados por una alta con – en citas (citas entre las clases del mismo grupo) y bajas entre las citas (citas entre clases de diferentes grupos).
- Una disminución en el número de clases citadas. Aquí una doble explicación es posible. Por un lado, esto significa que existe una disminución en el número total de clases tecnológicas siendo orientado a las patentes; bajo este tipo de hipótrabajo de investigación, y por otro lado se produce la especialización de tal manera que la complementariedad entre diferentes clases disminuyen con el

tiempo, empujando hacia una disminución en el número de clases citado, en promedio, por una patente.

Lo más importante a notar aquí es que, aparte del sector de los semiconductores, que es el que presenta el menor valor del índice en todo menos en un periodo, los otros sectores comienzan casi al mismo nivel (en torno a 0,5) en el primer período y entonces evolucionan de manera diferente. Telecomunicaciones experimenta el descenso más acusado y su valor del índice de ICTEB siempre se encuentra por debajo de los otros (excluyendo Semiconductores). Automotores y productos farmacéuticos presentan un comportamiento más suave, con este último nunca rompiendo el 0,4 límite inferior. Una característica interesante adicional consiste en el análisis de la mayoría de las tendencias recientes de complejidad tecnológica si los comparamos con respecto a los que se encuentran en el restante de la muestra. En las primeras décadas de la muestra en la gran mayoría de sectores se muestra claramente una tendencia a la disminución en la complejidad tecnológica de las patentes y, además, este comportamiento es evidente también a nivel de empresa, y no sólo cuando agregamos las actuaciones de las EMN para obtener los sectoriales. Para los cambios en la situación contraria, cuando nos centramos en los últimos 10 años: el comportamiento del ICTEB a lo largo de los sectores son mucho más heterogéneo. En particular, es posible observar que el número de sectores que muestran un aumento de la complejidad tecnológica en las invenciones que la patente (Productos farmacéuticos y Telecomunicaciones) es igual al número de sectores con la disminución de ICTEB (vehículos automóviles y sus semiconductores). Otra parte, que la mayoría (12 /20) de las empresas muestran un aumento ICTEB, con las únicas empresas del sector automotriz que presenta un crecimiento negativo.

Hasta ahora el análisis presta atención hacia el comportamiento de los índices propuestos a nivel sectorial, tras la integración de las actuaciones específicas de una empresa en la versión a nivel sectorial del índice. Este enfoque proporciona evidencias generales en la medida en que las actividades de I + D difieren en todos los sectores de la producción que producen y en la composición de los grupos de investigación dedicados a la producción de este tipo de salida. Lo que surge es que las diferencias son mucho mayores que las afinidades, con la excepción de complejidad tecnológica de las patentes, que es la única dimensión a lo largo de la cual todos los sectores analizados exhiben el mismo patrón (decreciente).

Otra dimensión interesante está dada por una comparación de la variabilidad en torno a las tendencias sectoriales, entre un sector y otro. De tal manera que no sólo capturamos el desempeño del sector en su conjunto, sino que también podemos observar cómo las EMN de los sectores respectivos se desvían de la tendencia global.

Continuando por esta corriente y mantener fijado el periodo de análisis se observa que, con respecto al índice de IGI, los semiconductores es el sector con el mayor grado de homogeneidad, con todas las EMN relevantes que muestran patrones muy similares, mientras que de los vehículos automóviles y productos farmacéuticos multinacionales mostrar comportamientos del índice muy contrastantes, con las dos picos y valles.

Pasando a la ISTEM la imagen se invierte. Las EMN con un comportamiento más parecido son las que operan en los productos farmacéuticos, mientras que las empresas de automóviles y semiconductores muestran tendencias muy heterogéneas. Centrándose en cambio en el ISUB, el índice mide el grado de especialización de servicios públicos. Es análisis pone de manifiesto el comportamiento similar entre los mientras que Semiconductores y Telecomunicaciones muestran un patrón muy heterogéneo, siempre con no más de 2 firmas de más de 5 que tienen una tendencia análoga.

Con respecto a los últimos indicadores propuestos en este trabajo de investigación, los ICTEB, Semiconductores y Telecomunicaciones son de nuevo los dos sectores que presentan un mayor grado de heterogeneidad en el comportamiento de las EMN importantes, mientras que en los otros dos sectores cada empresa muestra un patrón muy similar a la otra.

Al concluir, es interesante destacar que, aparte de las diferencias sectoriales en el valor agregado de los cuatro índices propuestos en este trabajo, existe una fuente adicional de heterogeneidad intra – sectorial. Se administra por la variabilidad del comportamiento entre las EMN dentro de cada sector. En las telecomunicaciones en general y, en particular, semiconductores son los dos sectores con una variabilidad más pronunciada, tras llevar a cabo las empresas de muy diferentes maneras. La excepción está constituida por el caso de los más relevantes de nuestros índices, el Grupo, en donde las EMN que trabajan en semiconductores muestran una evolución muy homogénea de su actitud hacia la internacionalización y la globalización de las actividades de investigación. Este es un resultado importante: en la industria de semiconductores de I + D está estructurado de manera que las EMN reconocen la necesidad de más (o menos) los grupos de investigación geográficamente heterogéneas, pero, a pesar de esta similitud, el resultado de una investigación de este tipo es muy diferente en términos de tecnología clases de la patente objeto de análisis y las respectivas patentes citadas por el mismo.

Por otra parte, el mismo tipo de análisis se puede hacer para todos los otros sectores y, además, es posible subrayar si similitudes de comportamiento entre los cuatro índice. Nos gustaría destacar que este es otro punto fuerte de nuestro esfuerzo.

5.6 Las contribuciones a la literatura existente

Nuestro enfoque encuentra sustento teórico de forma parcial en la literatura existente. (Guellec y van Pottelsberghe de la Potterie, 2001; Picci, 2010; Montobbio y Sterzi, 2013). Aparte del hecho de que hoy hay disponibles más datos para el análisis que una década atrás, nuestra investigación difiere en muchos aspectos de la literatura anterior. Una dimensión en la que este trabajo es innovador es en su tratamiento de la información sobre patentes y el uso de la información sobre patentes para construir indicadores.

Podemos reclamar la validez, apoyada por la evidencia (explicada en el capítulo 2), de nuestro nuevo indicador de acuerdo con el uso de una base de datos de patentes transversal entre países como un estimador de la extensión de la internacionalización de la actividad inventiva, es decir, de la heterogeneidad geográfica de los inventores de los grupos de investigación. A diferencia de la gran mayoría de los estudios previos que proporcionan los indicadores de patentes entre los países, en este trabajo deliberadamente decidimos hacer caso omiso de los temas de la diferencia geográfica en la localización de las actividades de I+D y de la sede solicitante, así como de la colaboración internacional en I+D entre las empresas en general, sobre todo con el fin de centrarse en la composición geográfica de grupos de investigación.

Aunque estos temas son muy interdependientes y su estudio conjunto es probable que sea necesario en la búsqueda de una teoría general sobre la globalización de la I+D, nuestro objetivo aquí es dar un nuevo instrumento metodológico, compuesto por un índice general, el "índice de Inventores" Grupo de Internacionalización y tres índices específicos para las EMN: el índice de utilización Especifica de Patentes, el índice de complejidad tecnológica de patentes, el índice de especialización tecnológica de las EMN.

Afirmamos, también basándose en la evidencia (explicada en el capítulo 2), la validez de los índices similares de datos de patentes para producir medidas simples de dinámicas específicas que podrían ser utilizados como indicadores para el análisis de la actividad inventiva de las EMN y de cómo estas actividades difieren entre sectores.

Además, como se presentó en la sección anterior, nuestro análisis permite la comparación, entre los sectores, de la variabilidad con la que las actividades inventivas tienen lugar dentro de una industria. Esto proporciona un análisis más complejo, pero aún más informativo, de las diferencias sectoriales en la forma en las MNEs llevan a cabo sus actividades de I+D.

5.7 Conclusiones

En primer lugar, hemos estudiado y analizado las principales tendencias de la internacionalización de equipos de I+D en las EMN. La principal contribución de este trabajo es el desarrollo de un índice que ayuda a comprender la internacionalización de la producción y la difusión del conocimiento.

En segundo lugar, ya que el conjunto de datos utilizado cubre un período de casi 29 años, los resultados ayudan a tener un análisis profundo. La realización del análisis sobre la base del índice geográfico profundiza aún más el análisis y divide las patentes de acuerdo con la presencia de los inventores de países BRICS y de los tigres asiáticos, y aún más en su clase tecnológica.

Además, los resultados se analizan en cuatro grandes sectores: automotriz, productos farmacéuticos, telecomunicaciones y semiconductores. Además de considerar cuatro sectores claves, también se considera las fluctuaciones estructurales debido a las fusiones y adquisiciones experimentadas por cada sector. Este método es capaz de ofrecer resultados más confiables en comparación con las anteriores que asignan las patentes a las sociedades matrices suponiendo que no hay cambios estructurales en el tiempo. Los problemas relacionados con el enfoque más antiguo se basan en las características intrínsecas de la actividad que es estratégica y podría estar influenciada por los cambios en la estructura del grupo de patentes. Bajo el enfoque adoptado en este capítulo se descarta la aparición de estos problemas.

Por último, nuestro enfoque ofrece una dimensión adicional del análisis, que constituye en la comparación de la heterogeneidad intra–sectorial del comportamiento de las EMN a lo largo de las dimensiones propuestas. Para nuestro conocimiento este tipo de análisis no está abarcado por la literatura existente.

5.8 Limitaciones y futuras líneas de investigación

Este trabajo de investigación abre nuevas vías para la comprensión de la internacionalización de los equipos de I+D con la ayuda de los índices que utilizan las estadísticas de datos de patentes.

Este enfoque podría utilizarse más para comprender los antecedentes de la actividad de patentes y las consecuencias resultantes. Junto con esto, podría ser interesante explorar si las características de la actividad de patentes cambian con las condiciones del mercado o los gastos de los grupos.

Estas son algunas de las limitaciones y orientaciones para futuras investigaciones posibles:

- El uso de la Oficina Europea de Patentes no puede tener en cuenta muchas de las aplicaciones que pertenecen a los solicitantes de países en desarrollo que prefieren la USPTO como su primera oficina de patentes: la investigación futura podría abordar esta limitación mediante el uso de datos de patentes USPTO;

- El análisis realizado con el índice de internacionalización para el grupo de inventores podría tomar en cuenta la ciudadanía de los inventores, ya que estos datos son menos sensibles a los cambios: la investigación futura puede abordar esta limitación mediante el uso de la base de datos sobre la movilidad de los inventores (Miguelez y Fink, 2013);
- El análisis realizado con el índice de internacionalización para el grupo de inventores podría tomar en cuenta el origen étnico de los inventores: la investigación futura podría abordar esta limitación mediante el uso de la base de datos sobre el origen étnico de los inventores a través de un análisis de nombre–apellido (Fiscella y Fremont, 2006) También en relación con las políticas de inmigración de cada país;
- Una debilidad de este trabajo de investigación es el uso de una sola base de datos: la investigación futura puede abordar esta limitación mediante la conexión de las bases de datos de patentes con otras fuentes en micro y macro que permitan el análisis a través de modelos econométricos;
- El análisis de 20 EMN no nos permite evaluar con eficacia los efectos de las empresas en los sectores debido al insuficiente número de patentes concedidas: sería conveniente identificar un mecanismo (algoritmo) para la detección semiautomática de las EMN en la base de datos de patentes, ya que los mecanismos manuales tomarían mucho tiempo para interactuar con otras bases de datos;
- El uso de la clasificación OST30 no nos permite hacer un análisis comparativo adecuado con otros datos e información con la clasificación sectorial denominado ISIC : la investigación futura podría abordar esta limitación mediante la creación de un cuadro de concordancia basada en el enfoque probabilista para el análisis conjunto de las patentes;
- Se necesitan más investigaciones para analizar y comprender la razón de la disminución de la tendencia a la internacionalización de las actividades de invención de patentes que involucran países BRICS y tigres asiáticos desde 1994;
- Se necesitan más investigaciones para analizar y comprender la razón de la diferente velocidad en las tendencias de internacionalización de una tecnología.

El objetivo de este resumen extendido fue sintetizar el trabajo de investigación realizado en esta tesis doctoral, que se describe ampliamente en los tres capítulos anteriores y que se han realizado para optar al grado de Doctor en "Economía y Gestión de la Innovación", con la mención europea, en la Universidad Complutense de Madrid.

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6.4. Software

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STATA software (Version 12). Copyright, Stata Corportation LP., licensed to Università Commerciale "L. Bocconi", Milan (Italy).

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